Attention capture:

Stimulus, group, individual, and moment-to-moment factors contributing to distraction

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General Abstract

Over four studies, some containing multiple experiments, attention capture is explored in a variety of experimental contexts. The over-arching goals were to better understand attention capture at the stimulus level (Chapter 2), the group and the individual-differences level (Chapters 3 and 4), and in terms of moment-to-moment fluctuations in susceptibility to distraction by task-irrelevant stimuli (Chapter 5).

Rare or unexpected stimulus changes are known to capture attention and disrupt behavioural performance. Detection is typically thought to depend on changes to the physical properties (e.g., tone pitch) of a stimulus. Chapter 2 explores whether physical change is a necessary antecedent for attention capture. Here, evidence suggests that unexpected semantic change is sufficient to produce a distraction effect and that an accompanying physical/acoustic change is not required to induce semantic processing of task-irrelevant stimuli even when the semantic deviants are unrelated to the primary task.

Attention capture is typically robust at the group level and has been observed in a variety of popular paradigms. Chapter 3 explores whether attention capture can be viewed as a stable and generalizable individual trait. The study examined involuntary attention capture across a set of prototypical stimulus-driven capture tasks and contingent-capture tasks in both spatial and/or temporal paradigms. Results showed the expected pattern of capture in each of the tasks as well as modest to good test-retest reliability over the span of one week for each of the capture measures. However, no evidence is found for a common attention capture factor providing evidence that attention capture within an individual is reliable but not generalizable. Chapter 4 extends the results of Chapter 3 and shows that attention capture in these tasks is not related to off-line self-report measures of attentional ability and day-to-day functioning. The lack of evidence for a common factor that can predict attention capture in one or more paradigms suggests that attention capture is not characterized by trait individual differences in executive function or predicted by individuals' meta-awareness of their own attentional ability.

Chapter 5, however, shows that attention capture can be characterized by moment-to-moment lapses of attention as it varies trial-to-trial as a function of internally generated task-irrelevant thought (i.e., mind-wandering). Mind-wandering slowed RTs overall and increased non-contingent, but not contingent, forms of capture providing evidence that some forms of attention capture are exacerbated by moment-to-moment lapses of attention. Self-reports on a dispositional mind-wandering scale did not predict capture when mind-wandering was used as an individual differences variable. Results suggest that attention capture may be better explained by cognitive processes engaged moment-to-moment rather than individual dispositions.

Keywords: Attention, Distraction, Mind-wandering, Reliability, Capture

Chapter 1

General Introduction

Introduction

Attention is arguably the most important mechanism in human cognition. Without it, new memories cannot be formed, friends would be lost in crowds for an eternity, and even basic daily activities like driving a car or navigating the hallways of a large institution would fall apart instantly. Of course, any discussion of attention is inherently a discussion of selective attention. Because so much information is available to us at any given moment, and because the human brain is incapable of processing and responding to all of it, attention is necessarily required to sort out the material that is most relevant to our current goals and needs. The way in which humans are able to selectively attend to some material while simultaneously ignoring other irrelevant material has been the source of empirical study for well over a century (James, 1890). Driving a car is a classic example of selective attention in action. Safe driving requires a careful focus on avoiding other cars or pedestrians while ignoring an ongoing conversation with or between passengers in the car. Sometimes, selective attention fails to filter out task-irrelevant material and is needlessly diverted from processing goal-related material. This can lead to behavioural costs such as extended response times or reduced target detection accuracy, or in the case of driving, an accident. However, it is sometimes important to attend to distracting stimuli, and a similar breakdown in attentional filtering can also serve as a benefit. In the case of driving, a peripheral sudden visual onset may signal danger or an obstacle. Thus, the apparent inability to filter such a stimulus may serve to protect our survival. Therefore, the attentional system must strike a balance between attending to goal-relevant stimuli and sampling for potentially important stimuli that are outside the current goal-related focus. “Failures” of selective attention can be either beneficial or costly, but clearly the mechanisms are both complex and fallible.

Selective Attention

Early models of selective attention (Broadbent, 1958) placed an attentional filter between sensory input and cognitive mechanisms for processing stimulus meaning. Such an "early filter" was thought to differentiate relevant from irrelevant stimuli based on physical properties such as colour, shape, or pitch. It was only after this filter that stimuli would be processed for meaning. Dichotic listening studies (Cherry 1953; Broadbent 1958) supported this view. In a dichotic listening task, participants hear two separate voices each presented in one ear. Participants were instructed to selectively attend to, and repeat out loud, the message from one ear while ignoring the other ear. When questioned afterwards, participants were able to report when the physical characteristics of the unattended ear's message changed (e.g., pitch, pacing, loudness). However, the content of the speech messages presented in the unattended ear was not identified by the participants. Furthermore, participants did not detect changes to the messages even when the speech was played backwards.

Later studies (Moray, 1959; Wood & Cowan, 1995) found evidence that unattended content could bypass the filter if it was personally salient or related in some way to the primary task. For example, in the aptly named "cocktail party phenomenon" a participant's own name could be detected in the unattended channel and be reported even when they were unaware that it would be presented. Treisman (1960) extended this finding and showed that when the semantic content of attended and unattended messages was similar, shadowing of the attended message would be impaired. Thus, even ignored stimuli can reach consciousness if relevant to the listener or the task.

Deutsch and Deutsch (1963) pointed out that having two filters (one for physical properties and one for semantic content) was redundant. Instead, they proposed that physical and semantic characteristics are used simultaneously by the filter. Only the stimuli with the greatest activation would be processed further. This late selection account of selective attention argues for selection only after semantic processing has already occurred. To account for the dozens of findings supporting early selection models and the dozens of findings supporting late selection models, most attention researchers now posit that the locus of selection moves around depending on the nature of the task and the participant’s strategy such that selection takes place wherever it is most useful for it to take place (Johnston & Heinz, 1978; Lavie, 1995).

Attention Capture

Because attentional selection can be late, all stimuli may be processed for both low-level features and semantic properties. Thus, whether the task-irrelevant stimulus is simply a salient loud noise, sudden onset, sudden offset, or whether it is in some way related to the task or salient to the perceiver, it may evoke further attentional processing. Shifts of attention can occur voluntarily or involuntarily—a distinction that is critical within selective attention research. Posner (1980) proposed that there are two types of attentional orienting—exogenous and endogenous—where the exogenous type reflects rapid and automatic orienting in response to a salient stimulus such as a sudden onset, offset, or flash. For example, in the spatial cueing paradigm an exogenous cue such as a brightening box occurs in the periphery of attentional focus and attention quickly moves to the location of the cue, even if the cue is known to be independent of the location of the target and the required response (e.g., Posner, 1980). Endogenous orienting, by contrast, is characterized by comparatively slower, voluntary attentional orienting. For example, in the spatial cueing paradigm the participant can decide whether or not to follow an endogenous cue such as a centrally presented arrow that cues attention to the left or right side. Under such conditions, deployed attention is slower to reach the location than with exogenous cues, but also rests there longer once deployed. The key difference between these types of attentional orienting is that orienting to exogenous cues is rapid and involuntary whereas orienting to endogenous cues is slower and voluntary. Since Posner's original work, much has been done to characterize the properties of each type of orienting (e.g., Jonides, 1981; Müller & Rabbitt, 1989; Yantis & Jonides, 1984, 1990a), but for the purposes of the present set of experiments, the focus will be on the involuntary exogenous form of attentional capture.

For selective attention to function adequately, a balance must be struck between bottom-up and top-down processing. Low-level stimulus features drive bottom-up processing which is thought to function automatically regardless of task parameters, an individual's goals, or how attentional resources have been allocated (Posner & Raichle, 1994). This viewpoint argues for capture by stimulus salience alone. Some of the most salient stimuli are sudden flashes, rapid movement, and bright colours (Breitmeyer & Ganz, 1976; Müller & Rabbitt, 1989; Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, 2004). In a purely bottom-up manner any stimulus that is sufficiently salient, such as an abrupt onset/offset, flash, or colour singleton captures attention (at least initially) regardless of the nature of the task, the to-be-attended target, or the viewer's intentions (Burnham, 2007; Hickey, McDonald, & Theeuwes, 2006; Lange, 2005; Lavie, 2005; Rauschenberger, 2003; Schreij, Theeuwes, & Olivers, 2010; Theeuwes, 1991, 1992, 1994, 2010; Yantis & Jonides, 1984). For example, task-irrelevant abrupt onset stimuli are known to involuntarily capture attention even when they never predict target location (Remington, Johnston, & Yantis, 1992).

In one version of the Spatial Visual Search task (Theeuwes, 1994), participants are required to categorize the orientation of a line placed inside a target shape (e.g., a circle). The target circle is presented amongst an array of non-target squares. Additionally, all items may be presented in either red or green, but stimulus colour is irrelevant to the task and never predicts target location. In the distractor-absent condition, all the shapes are presented in the same colour (e.g., green or red); in the distractor-present condition, one non-target square is presented in a different colour from the target circle and other non-target squares. Although colour is an irrelevant dimension of the stimuli (only shape is required to differentiate targets from distractors), salient odd-colour distractors can capture attention and slow target identification as revealed by extended response times for distractor-present compared to distractor-absent conditions. Similarly, in a temporal search paradigm (Folk, Leber, & Egeth, 2002), distractors that share no features with targets can capture attention and manifest in reduced target identification accuracy. In this paradigm, individual letters are centrally presented one at a time in a Rapid Serial Visual Presentation style at a rate of about 10 items per second. Participants are instructed to identify a single coloured letter amongst the stream of gray letters with a button press at the end of each 20-item stream. Performance is gauged by the accuracy with which target coloured letters are identified. When no distractors are present, accuracy is generally high as the single odd-coloured letter stands out against a stream of gray letters. However, on distractor trials, a set of four hashtags (#) is presented above, below, left, and right of a non-target gray letter that precedes the odd-coloured target letter by two positions (200ms). The presence of these hashtags is associated with reduced target identification accuracy compared to the distractor-absent condition where no hashtags are presented. This is considered non-contingent because the features of the target and the distractor do not match. That is, the target odd-coloured letter is defined by its colour whereas the distractor is defined only by its presence. Capture in this case is produced predominately by exogenous sources whereby the processing of a non-specific distractor reduces target identification accuracy. Curiously, bottom-up attentional capture is not limited to feature-level characteristics. In some cases, the semantic content of the stimulus can capture attention in a similar way. Emotionally arousing words (Arnell, Killman, & Fijavz, 2007) or pictures (Most, Chun, Widders, & Zald, 2005) are known to capture attention automatically in the temporal search paradigm leading to reduced target accuracy.

The bottom-up, non-contingent viewpoint was disputed by Folk and colleagues (Folk, Remington, & Johnston, 1992; Folk & Remington, 2006; see also Gibson & Kelsey, 1998; Yantis & Jonides, 1984, 1990) who found that abrupt onsets would only capture attention if the viewer was also looking for targets that were defined by an abrupt onset. This contrasting contingent attentional capture viewpoint suggests that attention capture is not driven by stimulus salience alone but instead depends on the individual's search parameters. That is, the likelihood of capture by a task-irrelevant stimulus will depend largely on a participant's subjective saliency of that stimulus or the use of a stimulus-defining feature as part of their search set.

Returning to the example of Spatial Visual Search (Theeuwes, 1994), if the target circle is always green (and participants are told so), then colour becomes a defining feature of the target that participants can use to guide search. In this way, when a participant is looking for a green circle, other green objects in the search array are more likely to be processed and subsequently capture attention. The distractor-absent condition would contain a single green target circle amongst a set of non-target red squares, whereas the distractor-present condition would contain single target green circle amongst non-target red squares as well as a single non-target green square. The green distractor is made salient simply by the fact that it shares the colour feature with the target. Capture is reliably observed as longer RTs in the distractor-present condition compared to the distractor-absent condition (e.g., Folk et al., 1992), and this is referred to as contingent capture given that the capture by the distractor is contingent on it matching an element of the target search set.

A similar modification can be made to make a contingent version of the temporal visual search task (Folk et al., 2002). If the surrounding hashtags are coloured, instead of gray, then they would be capable of contingent capture attention and impair identification accuracy of the odd-coloured target letter. To the extent that individuals are using colour to guide their search for the odd-coloured letter, coloured hashtags should lead to lower target identification accuracy compared to the condition where the hashtags are all gray.

Perhaps the most telling example of contingent capture comes from the Involuntary Spatial Orienting task (Folk et al., 1992). For example, Folk et al., (1992) asked participants to identify the target presented in one of four pre-defined spatial locations demarked by a containing box. Prior to the onset of a target, a cue was presented. Cues could be of two types. In the onset cue condition, one of the containing boxes was illuminated white while the three remaining boxes stayed gray. In the colour cue condition, all four boxes were illuminated; three locations turned white and one location turned red. For both types of cues, the location of the cue could be valid (matched with location of target) or invalid (did not match the location of the target). The cues were valid on 25% of trials and therefore did not predict the location of the subsequent target. Capture by the cue is shown by longer RTs for invalidly cued trials than for validly cued trials.

In one experiment, targets were defined by the rapid onset of the “X” or “=” (e.g., their sudden appearance), and in another experiment the target was defined by colour rather than onset. In this task, only the onset cue condition shares a feature with onset targets; colour cues do not match the attentional set for the target, and only the colour cue condition shares a feature with colour targets as onset cues do not match the attentional set for the target. Thus, capture by onset cues is contingent on the development of an attentional set for onset features and capture by colour cues is contingent on the development of an attentional set for colour features. Typically, with onset targets capture is observed only for onset cues, but not colour cues, and with colour targets capture is observed only for colour cues but not onset cues.

In an effort to avoid distraction, an individual may set a (top-down) goal to ignore irrelevant material in favour of a primary task such as ignoring a loud conversation in the car while driving. However, because obstacles or dangers can present themselves at any moment, the driver cannot simply ignore everything he hears; at least some stimuli must be processed without strict filtering (e.g., another car's horn). In this way, one must maintain balance between focusing on the task and allowing some potentially important information through.

Capture by task-irrelevant stimuli has been shown to impair performance in a concurrent task in the form of response time or accuracy costs. However, the costs of capture are not limited to concurrent task performance as it is also known to impair subsequent memory for items held at the time of capture. For example, Lange (2005) found that unexpected changes in a task-irrelevant sounds lead to impaired memory for the concurrently presented visual stimulus. In this experiment, the digits 1 to 9 shown one at a time in a random order on a computer screen and participants were required to memorize them and to report them later. At the onset of each digit, an auditory tone was also played. Most of the time, the auditory tone was the same tone repeated; sometimes, and unexpectedly, the repeated tone was replaced by a different tone. Whenever this tone change occurred, later memory for the digit that was presented at the same time was impaired compared to the digits that were presented before the change. In line with Cowan's (1995) memory model, Lange (2005) argued that to-be-remembered visual content (i.e., the digits 1 – 9) is held temporarily in the focus of attention. If attention is captured by some unexpected physical change (e.g., the tone change) weaker encoding of to-be-remembered items results. Thus, capture costs can be quantified both as an online measure with response times and accuracy, as well as longer term costs in memory for items held in focus at the moment of distraction.

The distractors themselves can also take various forms. Many of the above-mentioned attention capture studies have used visual cues or distractors in visual tasks, but one can also define distractors as an unexpected auditory stimulus or change, as in Lange’s (2005) study discussed just above. In many cases (e.g., Berti et al., 2004; Berti & Schröger, 2003; Escera et al., 1998; Horváth & Winkler, 2010; Schröger et al., 2000; Schröger & Wolff, 1998; Schröger, 1996), the primary task has been auditory and so has the unexpected change, perhaps even embodying the same perceptual object. For example, the primary task might be to categorize auditory tones as being short or long duration while the task-irrelevant dimension of the tone (its pitch) changed unexpectedly (Berti et al., 2004; Berti & Schröger, 2003). Attentional shifts to the unexpected auditory changes come at the cost of processing task-relevant dimensions or targets, as reflected in extended response times and/or reduced accuracy on the primary task (Escera et al., 1998; Escera, Yago, Corral, Corbera, & Nunez, 2003; Parmentier, Elford, Escera, Andrés, & San Miguel, 2008; Parmentier, 2008, 2014; Schröger et al., 2000; Schröger & Wolff, 1998; Wetzel & Schröger, 2007). The nature of attention capture can also be cross-modal where the distractor is an auditory stimulus and the task is visual. Typically, cross-modal studies with auditory oddballs have asked participants to perform a simple visual task such as categorizing digits as odd or even, while irrelevant auditory stimuli are presented concurrently (Berti & Schröger, 2001; Escera, Yago, & Alho, 2001; Pacheco-Unguetti & Parmentier, 2014; Parmentier et al., 2008; Parmentier, 2014; Yago, Corral, & Escera, 2001). In these studies, auditory distractors are defined by their unique, non-contingent, physical properties (e.g., pitch, location, or timbre), but can also be contingent on the task parameters (e.g., the spoken word “left” or “right” when categorizing visually presented arrows pointing to the left or the right; Parmentier, 2008), or on the participant (e.g., one’s own name), though some studies have failed to find capture effects under these conditions (e.g., Ljungberg, Parmentier, Hughes, Macken, & Jones, 2012; Ljungberg, Parmentier, Jones, Marsja, & Neely, 2014).

Individual Differences in Attention Capture

Despite the large number of studies investigating non-contingent and contingent attention capture, there have been few studies that have attempted to understand attention capture by examining individual differences in attention capture. A small number of studies have investigated measures or tasks that predict one’s tendency to be captured by task-irrelevant stimuli within a single capture paradigm. One measure that has been used successfully is working memory capacity which is thought to underlie a wide range of complex cognitive abilities and executive functions like reading, problem solving, and overall intelligence (Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2002, 2003). Conway, Cowan and Bunting (2001) used the classic cocktail party phenomenon of Moray (1959) and showed that individuals with relatively low working memory capacity, (as measured by the Operation Span task of Turner and Engle (1989) which measures the ability to hold items in memory while vocally stating and managing distracting material), are more likely to detect their own name in an auditory message played in the task-irrelevant ear, suggesting that those with low working memory have a reduced ability to inhibit or ignore task-irrelevant distracting material. A similar pattern has been observed in the visual domain where individuals with relatively low visual working memory capacity show relatively poor filtering efficiency by allowing more task-irrelevant items into visual working memory than those with higher visual working memory capacity (e.g., Arnell & Stubitz, 2010; Vogel, McCollough, & Machizawa, 2005). The finding that the tendency to be captured by, or the inability to resist processing of, irrelevant stimuli is related to working memory suggests that there may be common variance shared between attention capture measures and a more general attentional control factor that varies reliably across individuals.

The use of individual differences studies to look for general attention abilities is relatively new. Two recent studies (Huang, Mo, & Li, 2012; Skogsberg, Grabowecky, Wilt, Revelle, & Street, 2012) have looked for general attention factors across a variety of common attention paradigms such as visual search and multiple object tracking (Pylyshyn & Storm, 1988). Although performance measures were, at best, modestly correlated across tasks in both studies, Huang et al. (2012) reported a general attention factor underlying task performance across their tasks and described this factor as a flexible, task-agnostic, resource that can be used in various paradigms. Skogsberg et al. (2015) reported that individual attention performance across tasks could be organized along two dimensions: one that contrasts along spatiotemporal to global attention, and another dimension that contrasts along transient to sustained attention.

Neither of the above studies included attention capture tasks *per se*, but Kawahara and Kihara (2011) examined individual differences in attention capture using two attention capture tasks (Folk, Leber, & Egeth, 2002; Theeuwes, 1994) and the attentional blink task (Raymond, Shapiro, & Arnell, 1992). They found that individual differences in capture estimates from the temporal capture task were unrelated to capture estimates from the spatial visual search task, arguing for separable underlying cognitive processes and against a general attention capture factor. Furthermore, capture estimates were unrelated to performance on the attentional blink task.

Taken together, there is some inconsistency in terms of whether attention capture can be generalized across capture tasks and whether capture is a real individual trait. Over four studies, some containing multiple experiments, attention capture is explored in a variety of contexts. The over-arching goal is to better understand attention capture at the stimulus level, the group level, the individual differences level, and in terms of moment-to-moment fluctuations in susceptibility to distraction by task-irrelevant stimuli. The present body of work contains a popular cross-modal capture task (Chapter 2) and some of the most widely used non-contingent and contingent attention capture tasks (Chapters 3, 4, & 5). Each study is outlined below.

Overview of Studies

Chapter 2

The purpose of the two experiments in Chapter 2 was to determine a boundary condition for task-irrelevant auditory distractors. It is well-established that sudden unexpected physical changes to an auditory stimulus (e.g., pitch, location, or timbre) are sufficient to capture attention away from a visual task leading to response time and/or accuracy costs as well as memory impairment for any to-be-remembered visual targets presented at the time of the auditory change (e.g., Berti et al., 2004; Berti & Schröger, 2003; Escera et al., 1998, 2003; Lange, 2005; Parmentier et al., 2008; Parmentier, 2014). Here, the question of whether such a change must be physical or whether unexpected semantic change is sufficient to produce capture effects is tested. If semantic processing occurs automatically for irrelevant auditory distractors, as suggested by late selection models of selective attention, and the detection of semantic categorical change captures attentional resources obligatorily, then performance costs in an unrelated visual task should be observed. However, if semantic processing for irrelevant auditory distractors occurs only when accompanied by a novel physical change, then no performance differences should be observed. Previous studies have explored behavioural performance costs for semantic change detection, but in all cases, these experiments have either examined the influence of semantic information for physically deviant items (e.g., Escera et al., 2003; Ljungberg et al., 2012, 2014; Ljungberg & Parmentier, 2012; Parmentier, Elsley, Andrés, & Barceló, 2011) and/or used semantic deviants that were related to the primary visual task (e.g., Parmentier et al., 2011; Parmentier, 2014). Chapter 2 shows evidence to suggest that unexpected semantic change in irrelevant auditory distractors can produce attention capture, provided that the stimulus is seen as sufficiently semantically interesting, and that an accompanying physical/acoustic change is not required to induce semantic processing of task-irrelevant stimuli even when the semantic deviants are unrelated to the primary task.

Chapter 3

Chapter 3 uses an individual differences approach to examine the reliability and generalizability of attention capture using a set of three well-known and documented attention capture paradigms that each provide a non-contingent capture estimate and a contingent capture estimate (Folk et al., 2002; Folk, Leber, & Egeth, 2008; Folk et al., 1992; Theeuwes, 1991, 1994). These tasks were selected because they are prototypical examples of contingent and non-contingent capture. Additionally, they permit the direct comparison of contingent with non-contingent capture within each paradigm because the tasks are essentially the same except for the relationship between the distractor and target. For example, two versions of a spatial visual search task are used that are identical in all ways except for the critical distractor in each. In the non-contingent version, distractors share no features with the target and are thus simply odd colour singletons in the search array. By contrast, the contingent version uses a critical distractor that shares the feature of colour with the target. The full set of tasks used here produces a set of six separate measures of attention capture in spatial and temporal domains (contingent and non-contingent measures for each of three tasks). Each of these tasks is known to produce robust capture at the group level. As a result, many researchers in the field may tacitly assume that all capture tasks are essentially interchangeable. Here the focus is on whether attention capture statistically generalizes between tasks and capture measures and whether capture remains a stable individual trait over time within task/measure. Chapter 3 provides new evidence that attention capture in these tasks is stable both within a single experimental session and over the span of one week. However, no evidence is found for a common attention capture factor across measures. This is an important finding as it serves as a warning that attention capture tasks cannot simply be used interchangeably.

Chapter 4

Based on the findings of Chapter 3 that capture estimates are reliable over time within capture tasks, Chapter 4 includes the same set of attention capture tasks with the goal of predicting who will show more or less attention capture. Performance-based metrics such as scores on an executive control of working memory task (OSPAN; Turner & Engle, 1989) and other off-line self-report measures of attentional ability and day-to-day cognitive functioning are included. Across two studies using separate participant samples, and a large battery of well-known self-report estimates of attention ability, robust group-level attention capture in each task was observed. However, no measure, or constellation of measures, convincingly predicted individual-level attention capture performance.

Chapter 5

Chapter 5 examines whether moment-to-moment variability in attentional focus can predict trial-to-trial differences in attention capture. This was done by periodically asking participants whether they were on-task (not mind-wandering) or off-task (mind-wandering) while they performed both the contingent and non-contingent visual search tasks used in Chapter 3 and 4. Participants also completed a mind wandering questionnaire (the Mind-wandering Spontaneous and Deliberate Scale; Carriere, Seli, & Smilek, 2013) that asked about their general tendency to engage in spontaneous or deliberate mind-wandering episodes.

There is evidence that episodes of mind-wandering are associated with default network activation (e.g., Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Mason et al., 2007), careless performance in a sustained attention task akin to driving (Smallwood et al., 2004), impaired day-to-day cognitive functioning (McVay, Kane, & Kwapil, 2009), reduced reading comprehension (e.g., Kane & McVay, 2012), increased errors in vigilance in speeded response tasks (e.g., go/no-go tasks; Kane & McVay, 2012) and with general susceptibility to distraction (Forster & Lavie, 2014). Thus, moment-to-moment mind-wandering estimates appear to make an ideal candidate for predicting on-line capture.

I observed that attention capture can be characterized by moment-to-moment lapses of attention in that non-contingent capture was larger on trials where mind-wandering was reported than on trials where no mind-wandering was reported. However, trait level mind-wandering did not predict capture estimates. These findings suggest that limiting the prediction of attention capture to group-level differences may ignore a critical component of attention capture. There may be processes engaged moment-to-moment that are not reflected in derived overall capture scores.

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Chapter 2

Capture by unexpected change:

Semantic processing of irrelevant auditory stimuli is automatic and disruptive

Introduction

Daily life is filled with distractions. As commonly experienced in day-to-day functioning, some things must be selectively attended while ignoring others. For example, when driving a car one must attend to the stimuli associated with driving while ignoring distracting stimuli not associated with driving. In many cases, a distracting stimulus such as a flashy billboard or an alert for an incoming text message on a cell phone can relatively easily be categorized as to-be-ignored. However, sometimes, a stimulus such as a car horn requires further processing before it can be determined whether it is a relevant or irrelevant stimulus.

Surprising or otherwise unexpected auditory changes in our environment are known to produce a cascade of rapid and automatic brain responses thought to represent the detection of the change (e.g., Näätänen, Gaillard, & Mäntysalo, 1978; Näätänen, Paavilainen, Rinne, & Alho, 2007; Näätänen, 1992), the involuntary orientation of attention towards to the change (Friedman, Cycowicz, & Gaeta, 2001), and the reorientation of attention back to the primary task (Berti & Schröger, 2001; Escera, Yago, & Alho, 2001). In general terms, these attentional shifts to unexpected auditory changes come at the cost of processing task-relevant stimuli (Escera, Alho, Winkler, & Näätänen, 1998; Escera, Yago, Corral, Corbera, & Nunez, 2003; Parmentier, Elford, Escera, Andrés, & San Miguel, 2008; Parmentier, 2008, 2014; Schröger, Giard, & Wolff, 2000; Schröger & Wolff, 1998; Wetzel & Schröger, 2007). Typically, these costs come in the form of extended response times and/or reduced performance accuracy in a primary task (e.g., Berti & Schröger, 2003; Schröger, 1996).

In many cases (e.g., Berti et al., 2004; Berti & Schröger, 2003; Escera et al., 1998; Horváth & Winkler, 2010; Schröger et al., 2000; Schröger & Wolff, 1998; Schröger, 1996), the primary task has been auditory and so has the unexpected change, perhaps even embodying the same perceptual object. For example, the primary task might be to categorize auditory tones as being short or long duration while the task-irrelevant dimension of the tone (its pitch) changed unexpectedly (Berti et al., 2004; Berti & Schröger, 2003). However, the effect of unexpected auditory changes on electrophysiological components and behaviour is not limited to auditory combinations alone, as such effects have also been observed in cross-modal paradigms where the irrelevant distractor is auditory and the primary task is visual (Andrés, Parmentier, & Escera, 2006; Bendixen et al., 2010; Escera et al., 2003; Ljungberg & Parmentier, 2012; Parmentier et al., 2008; Parmentier, Elsley, & Ljungberg, 2010). Here we concern ourselves with irrelevant auditory stimuli influencing performance in an unrelated visual task (often referred to as a cross-modal oddball task).

Typically, cross-modal studies with auditory oddballs have asked participants to perform a simple visual task such as categorizing digits as odd or even, while irrelevant auditory stimuli are presented concurrently (Berti & Schröger, 2001; Escera et al., 2001; Pacheco-Unguetti & Parmentier, 2014; Parmentier et al., 2008; Parmentier, 2014; Yago, Corral, & Escera, 2001). Auditory stimuli are usually simple tones such as that generated by a sine wave (e.g., Boll & Berti, 2009; Escera et al., 2001; Yago et al., 2001), but may also be more complex sounds like a telephone ring and other identifiable environmental sounds (Bendixen et al., 2010; Escera et al., 1998, 2003), or spoken words (e.g., Ljungberg, Parmentier, Jones, Marsja, & Neely, 2014; Parmentier, 2008). The auditory stimuli are presented such that the same auditory stimulus is repeated trial-to-trial (e.g., a 500ms sine wave tone at 440hz). However, on comparatively rare trials, this repeated stimulus is replaced by a tone of a different frequency (e.g., 600hz or 200hz), duration (300 or 700 ms), timbre (a note from a flute), or white noise. When this rare/novel auditory stimulus is presented, performance in the primary visual task is temporarily disrupted and an extended response time is observed. Thus, the capture or distraction effect is defined by the difference in visual task performance on trials where an expected versus a rare/novel auditory stimulus is presented.

In studies investigating the effect of irrelevant auditory deviants on visual task performance, these so-called deviants are almost always deviant by virtue of changes to their physical properties (e.g., pitch, pacing, or timbre; see Parmentier, 2014, for an overview). Thus, it is clear that various physical changes to irrelevant auditory stimuli are sufficient to capture attention away from a primary visual task. What remains to be tested is whether physical change is a necessary antecedent for attentional capture, or whether semantic changes alone can capture attention in the absence of a physical change.

Unexpected auditory stimuli are given priority access to attentional resources and are processed in an obligatory fashion (Banbury, Macken, Tremblay, & Jones, 2001; Escera et al., 1998). Their detection can direct attention for further semantic processing (Ljungberg et al., 2014; Parmentier, 2008). Indeed, some researchers have claimed that semantic analysis of a task-irrelevant auditory stimulus will only follow its detection as a physical/acoustic deviant (Escera et al., 2003; Naatanen, 1990, 1992; Parmentier, 2008; Wetzel & Schroger, 2007). However, there are only a handful of experiments that have investigated behavioural performance costs for semantic deviants, and in all cases these experiments have either 1) examined the influence of semantic information for physically deviant items (Escera et al., 2003; Ljungberg & Parmentier, 2012; Ljungberg, Parmentier, Hughes, Macken & Jones, 2012; Ljungberg, Parmentier, Jones, Marsja & Neely, 2012; Parmentier, 2008; Parmentier, Turner, & Elsley, 2011; Parmentier et al., 2014), and/or 2) used semantic deviants that were related to the primary visual task (Parmentier, 2008; Parmentier et al., 2011; 2014).

For example, Escera and colleagues (Escera et al., 2003) found that deviant environmental sounds rated as identifiable produced extended RTs in a visual digit categorization task compared to equally deviant environmental sounds rated as non-identifiable, and standard tones. This suggests that novel stimuli are processed for meaning/significance once they have captured attention as physical deviants, as claimed by Escera et al. (2003). However, given that the novel sounds differed physically from the standard tones, these findings do not address the question of whether attention could be captured by semantic information alone.

Other studies have failed to find semantic effects for physically deviant novel stimuli. For example, Ljungberg et al. (2014) showed that one’s own name and matched control names showed equally large behavioural performance costs when presented as novels amongst tones in a cross-modal oddball task. Similarly, Ljungberg and Parmentier (2012) showed that neutral and emotionally negative words presented as novels amongst standard tones had equally large effects on visual categorization performance. However, as above, because the semantic effects were examined for physically novel stimuli, these findings do not address the question of whether attention could be captured by semantic information alone.

Parmentier (2008) also investigated whether there was semantic processing of physically deviant stimuli once they had captured attention. Participants were required to categorize visually presented arrows as pointing to the left or right. Direction was indicated with a button press using the left or right index finger, respectively. Participants performed this task while auditory distractors were presented just prior to the onset of each visual target. Standard auditory items (80% of trials) were sine wave tones. Deviant auditory items (20% of trials) were comprised equally of the words “left” or “right”, duration-matched to the tones. Results indicated that both congruent and incongruent novels produced longer visual categorization RTs compared to standard tones (the novelty effect), but that incongruent novels (e.g., voice saying “left” while the visual target pointed right) showed longer visual categorization RTs than congruent novels (e.g., voice saying “left” and the visual target pointing left) demonstrating semantic processing of these novel stimuli. The same pattern of results was observed when the standard stimulus was changed to the word “up”, indicating that the effects were not driven by the lexical novelty of the novel items.

Interestingly, Parmentier (2008) showed that when the roles were reversed and the word “left” or “right” was presented as the standard and a tone as novels, no congruency effect was observed by participants, only longer RTs overall for novel tones. Parmentier (2008) posited that semantic processing occurred only for deviant or unexpected irrelevant auditory stimuli once attention had been captured by their physical novelty (i.e., that prior attention capture was necessary to observe behavioural effects of semantic processing). However, note that congruency of the standard was a between-subjects manipulation and that a given participant would never experience both congruent and incongruent trials. Because of this design, the repeated presentation of a task-irrelevant word (e.g.,“left”) could lead to something akin to semantic satiation such that the word essentially loses its meaning and subsequently its ability to impact performance in semantic tasks (Balota & Black, 1997; Kounios, Kotz, & Holcomb, 2000; Smith & Klein, 1990; Smith, 1984). Thus, the null congruency effect found by Parmentier (2008) cannot unequivocally rule out automatic semantic processing of task-irrelevant stimuli.

In a recent follow-up study, Parmentier et al. (2014) repeated the Parmentier (2008) experiment where white noise bursts and the words “left” and “right” were novels presented amongst standard tones during which participants categorized arrows as pointing left or right. However, for some participants the auditory items consistently and accurately predicted the temporal occurrence of the subsequent visual item as in previous experiments (the informative condition), and for others it did not (uninformative condition). Interestingly, a novelty effect (longer RTs for novels than standards) was observed only in the informative condition, but a semantic congruency effect (longer RTs for incongruent pairing of the visual stimulus direction and the spoken word relative to congruent pairings) was found for both conditions, but was larger for the informative condition. Observing a smaller, but significant, semantic effect, even in the uninformative condition led Parmentier to revise his conclusion about semantic processing and conclude that semantic processing of auditory deviants reflects two sources: one which is dependent on prior attention capture as a deviant, and one which is not. Note however, that in both the informative and the uninformative condition the novel "left" and "right" words were still physically deviant from the standard tones. Importantly, these words also matched the left/right response set for the primary visual task. Given that the deviant words "left/right" are contextually related to the arrow categorization task, their detection may be facilitated by the development of a related attentional set (e.g., Goodhew, Kendall, Ferber, & Pratt, 2014). Therefore, these findings do not address the question of whether attention could be captured by task-irrelevant semantic information alone.

Thus, the purpose of the following experiments was to determine whether, in an auditory stream of words, unexpected changes in semantic content alone are sufficient to elicit capture effects when the semantic content of the auditory words and the visual task are unrelated. If semantic processing occurs automatically, and the detection of semantic categorical change captures attentional resources obligatorily, then a performance cost should be observed in an unrelated visual task. However, if semantic processing occurs only when accompanied by a novel physical change, then no performance difference should be observed.

In the following experiments, three possible loci for a semantic deviance effect are tested: 1) *Within-category novelty.* This is novelty based on the frequency with which the stimulus is presented during the experimental session. For example, in a context based on the repeated presentation of a set of animal species names, an infrequent novel would be an animal species that was not part of the typical set. 2) *Category change*. This combines frequency-based novelty with semantic categorical novelty. For example, in a context based on the repeated presentation of a set of animal species names, a category novel would be a non-animal word from a category such as vehicles. 3) *High arousal category change.* This combines frequency-based novelty with semantic categorical novelty and adds an emotionally high arousal component. For example, in a context based on the repeated presentation of a set of animal species names, the high arousal novel would be a sexually explicit word.

In the following experiments, a typical visual digit categorization task was used where participants classified the digits 1-8 as odd or even as quickly and as accurately as possible. In line with previous studies (e.g., Escera et al., 2003), task-irrelevant auditory stimuli were presented via headphones 200ms prior to the onset of each visually presented target digit. Auditory stimuli in Experiment 1 consisted of high frequency (i.e., frequency of occurrence in the experimental context) animal names standards (80% of trials), contextually novel animal names (10% of trials) and contextually novel non-animal nouns (10% of trials). In Experiment 2, auditory stimuli consisted of high frequency animal names (80% of trials), contextually novel animal names (10% of trials) and contextually novel taboo words (10% of trials). Response times and accuracy to the visual digits were collected.

If irrelevant auditory stimuli are not automatically processed for meaning during a visual task, unless they are physically deviant, then performance costs should not be observed on the visual task when semantically deviant items are presented. However, if irrelevant auditory stimuli are automatically screened for meaning during a visual task then delayed RTs and/or decreased accuracy should be observed for the visual task when semantically deviant items are presented. The present studies will allow the examination of whether semantic deviants can capture attention when 1) they are unexpected instances within the same semantic category, 2) from a different, emotionally neutral semantic category, and 3) from a different and emotionally arousing semantic category.

Experiment 1

Method

Participants. Twenty undergraduate students (15 female) at Brock University participated in exchange for research hours for a course. All participants reported normal or corrected-to-normal visual acuity and none reported any hearing impairment. The study received ethics clearance from the Brock University Research Ethics Board.

Stimuli. All experimental stimuli were presented via a Dell desktop computer running E-Prime (v1.1; Schneider, Eschman, & Zuccolotto, 2002). Visual stimuli were presented centrally in 18-point black Courier font on a white background using a 17-in CRT monitor with a refresh rate of 75 Hz. Visual stimuli were approximately 1 cm high by 1 cm wide. From an unfixed viewing distance of 50 cm, the visual angle of each digit stimulus was approximately 1.2° in height and width. Digits were individual digits from 1-8. Each digit was selected randomly with the constraint that the same digit would not be shown twice in a row.

The task-irrelevant auditory stimuli were comprised of single syllable words spoken in a monotone female voice. Recordings were generated for 28 monosyllabic animal names (e.g., Cat, Dog, Fish) and 20 monosyllabic non-animal words[1] (e.g., Car, Rock, Shoe). During recording, the speaker, a professional vocal coach, was encouraged to maintain identical pitch, velocity, and amplitude for each word. Nonetheless, recordings of each word were digitally matched for volume and duration to 500ms.

All stimuli were presented in a random order. All words were presented binaurally via noise-reducing headphones at a sound pressure level of approximately 70-75 dB. Participants reported that the auditory stimuli were clearly audible and at a comfortable volume.

Design and Procedure. A within-subjects design was used in which all participants were exposed to all three conditions: high frequency animal name (80% of trials), low frequency animal name (10% of trials), and low frequency non-animal word (10% of trials). For each participant, eight animal names were selected randomly from the pool of 28 animal names for use as the high frequency stimulus (each shown 20 times in experiment) and 20 animal names were selected randomly for use at the low frequency stimuli (each shown once per participant). All 20 non-animal words were presented to each participant (each word shown once per participant).

Participants were informed that a single digit between 1-8 would be presented on screen. They were instructed to identify whether the digit was an odd number (press the “z” key) or an even number (press the “m” key) as quickly and as accurately as possible. Participants were also informed correctly that they would hear spoken words via a pair of headphones which in no way predicted the digit identity or correct response, and that they should simply ignore the words and concentrate on identifying the digits.

[1] Word frequency estimates are difficult to validly apply here as taboo words do not regularly appear in newspapers (a common source for ascertaining word frequency estimates). Instead selection was focused primarily on simple, easily understood, monosyllable words that withstand temporal compression while maintaining auditory clarity.

Each trial was preceded by a fixation cross presented in the centre of the screen. This fixation cross remained on the screen for 200, 400, 600, 800, 1000, or 1200 milliseconds. Fixation duration was determined randomly for each trial. A 200ms blank screen followed fixation regardless of fixation duration. At this time, the auditory stimulus (e.g., one of the task-irrelevant animal names) was presented. Following the 200ms blank screen, the to-be-identified digit was presented and remained onscreen until a response was logged. Because the duration of the auditory stimulus was 500ms and the blank screen between fixation and the onset of the visually presented target digit was 200ms, the auditory and visual stimuli overlapped by approximately 300ms. A 400ms blank screen followed each response before the fixation cross for the next trial was displayed. Note that the onset of each task-irrelevant auditory stimulus preceded visual target stimulus by 200ms on each trial. The phenomenological onset of the auditory stimulus varied with each word according to the inherent rise or fall time of different words. Thus, the ISI between the fixation and the onset of the task-irrelevant auditory stimulus may have varied slightly.

The experimental session began with 16 practice trials during which time each of the high frequency animal names was presented twice in random order. These practice trials also allowed participants to come to view the frequent animal names as normative. This was followed by 200 experimental trials with the opportunity for a short break provided after 100 trials. The entire experimental session lasted approximately 30 minutes.

Results

Mean response times (RTs) for digit categorization were subjected to a one-way repeated-measures ANOVA whereby task-irrelevant auditory stimulus condition was contrasted.

Results indicated that auditory word condition did not impact digit categorization RTs, $F(2, 38) < 1$ (See Figure 2-1a).

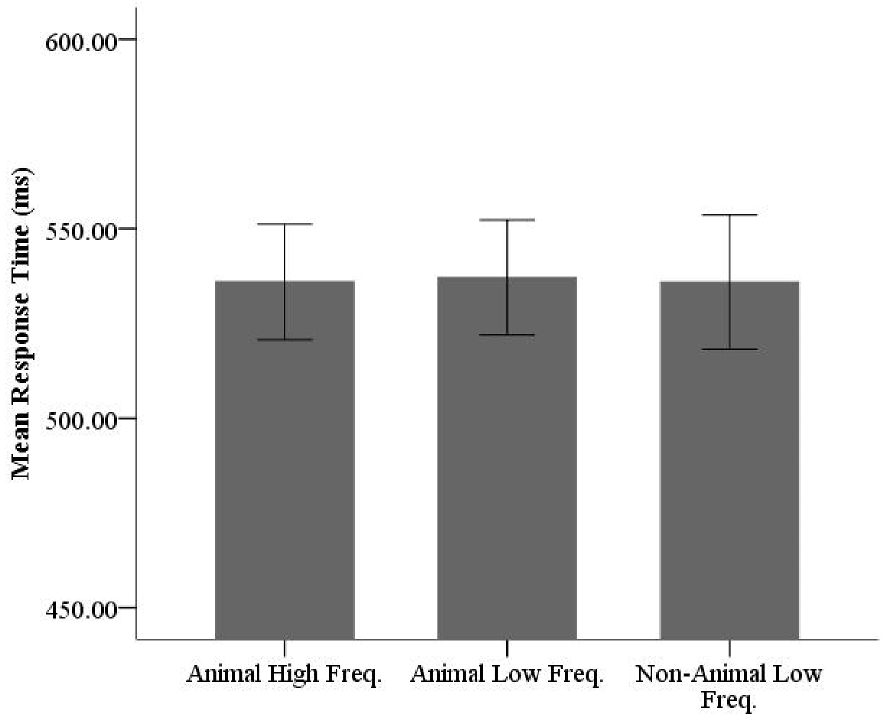

Figure 2-1a. Mean digit categorization response time in milliseconds (ms) as a function of irrelevant spoken word condition. Error bars represent one standard error of the mean.

A similar one-way ANOVA was conducted on digit categorization accuracy as a function of the same task-irrelevant spoken word conditions. Results indicated that mean visual target accuracy was not affected by task-irrelevant spoken word condition, $F(2, 38) < 1$. See Figure 2-1b.

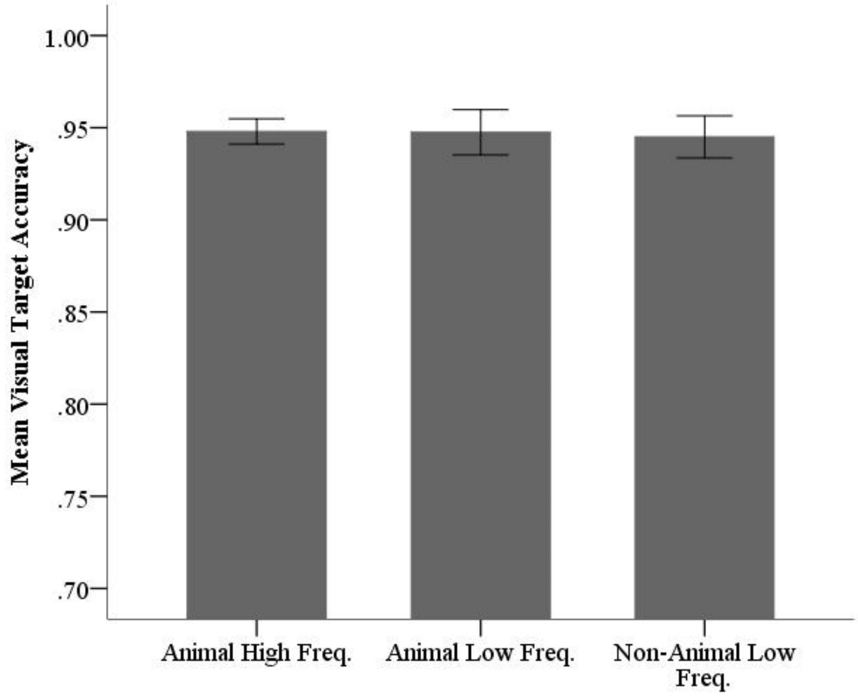

Figure 2-1b. Mean digit categorization accuracy as a function of irrelevant spoken word condition. Error bars represent one standard error of the mean.

Experiment 2

In Experiment 1, no evidence is found for capture by an unexpected semantic change. Task-irrelevant semantic change alone was not sufficient to produce a capture effect. One possibility for the failure to find an effect was that the task-irrelevant stimuli were low arousal words that carried little information that might be deemed important. It is possible that these items were detected and processed for meaning but were not permitted access to executive cognitive resources given their relatively low task or environmental significance. Experiment 2 tests whether semantic change based on highly arousing taboo words is sufficient to capture attention.

High arousal sexual/taboo words have previously been shown to influence task performance when presented as distractors in paradigms such as RSVP (Arnell, Killman, &

Fijavz, 2007; Mathewson, Arnell, & Mansfield, 2008), Stroop (MacKay et al., 2004), and Digit Parity (Aquino & Arnell, 2007). Thus, one might reasonably expect that these high arousal words would capture attention in the present paradigm.

Method

Participants. Nineteen different undergraduate students (16 female) at Brock University participated in this experiment in exchange for research hours for a course. None of them participated in Experiment 1. All participants reported normal or corrected-to-normal visual acuity and none reported any hearing impairment. The study received ethics clearance from the Brock University Research Ethics Board.

Stimuli. All visual stimuli were identical to Experiment 1. However, the task-irrelevant auditory stimuli differed. High frequency and low frequency monosyllabic animal names were selected randomly from the same pool of words as in Experiment 1. However, the list of low frequency non-animal words was comprised of 20 highly arousing taboo words instead (see Chapter 2 Appendix). Taboo words were selected based on the following criteria. They were the top 20 monosyllabic words with the highest arousal ratings from our emotional word database. Previous attention capture effects for emotional words presented visually have shown that arousal, not valence, is the critical factor predicting attention capture (Aquino & Arnell, 2007; Arnell et al., 2007). Using the same participant pool, previous work from our lab (Aquino & Arnell, 2007; Arnell et al., 2007; Mathewson et al., 2008) has shown that our taboo words are significantly higher in arousal, but do not differ in average valence, compared to neutral word sets. All 20 non-animal sexual/taboo words were presented once to each participant. Recordings of these words were spoken by the same female vocalist as in Experiment 1 and were volume and duration matched to all the stimuli from Experiment 1. All words were presented randomly as in Experiment 1.

Design and Procedure. The same within-subjects design as Experiment 1 was used where all participants were exposed to all conditions. The three task-irrelevant auditory word conditions were high frequency animal name (80% of trials), low frequency animal name (10% of trials), and low frequency non-animal taboo word (10% of trials). Procedures were otherwise identical to Experiment 1.

Results

Mean RTs to digit categorization were subjected to a one-way repeated-measures ANOVA whereby task-irrelevant auditory stimulus condition was contrasted. Results indicated that auditory word condition significantly impacted digit categorization RTs, $F(2, 36) = 3.41$, $p = .044$, $\eta_p^2 = .16$ (See Figure 2-2a). Follow-up paired-samples t-tests indicated that visual target RTs in the high frequency versus low frequency animal word conditions were not significantly different, $t(18) < 1$. However, visual digit target RTs that followed sexual/taboo words were significantly longer than visual digit RTs that followed the low frequency animal names, $t(18) = 2.10$, $p = .050$, $d = .35$, and longer, though not significantly than digit RTs that followed high frequency animal names, $t(18) = 1.84$, $p = .083$, $d = .30$.

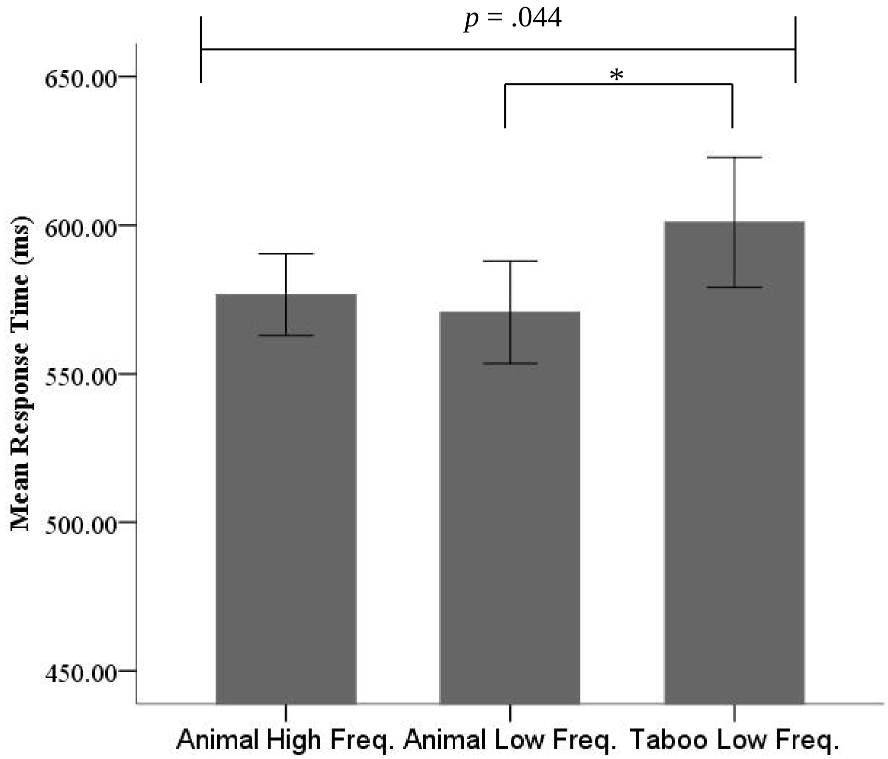

Figure 2-2a. Mean digit categorization response time in milliseconds (ms) as a function of irrelevant spoken word condition. Error bars represent one standard error of the mean.

A similar one-way ANOVA was conducted on digit categorization accuracy as a function of the same task-irrelevant spoken word conditions. Results indicated that mean visual target accuracy was affected by task-irrelevant spoken word condition, $F(2, 36) = 4.36$, $p = .020$, $\eta_p^2 = .19$. See Figure 2-2b. Follow-up paired-samples t-tests indicated that mean visual digit accuracy in the high frequency versus low frequency animal word conditions were not significantly different, $t(18) < 1$. However, visual digit accuracy was significantly lower following taboo words compared with high frequency animal names, $t(18) = 2.70$, $p = .015$, $d = .57$, but not low frequency animal names, $t(18) = 2.08$, $p = .053$, $d = .34$.

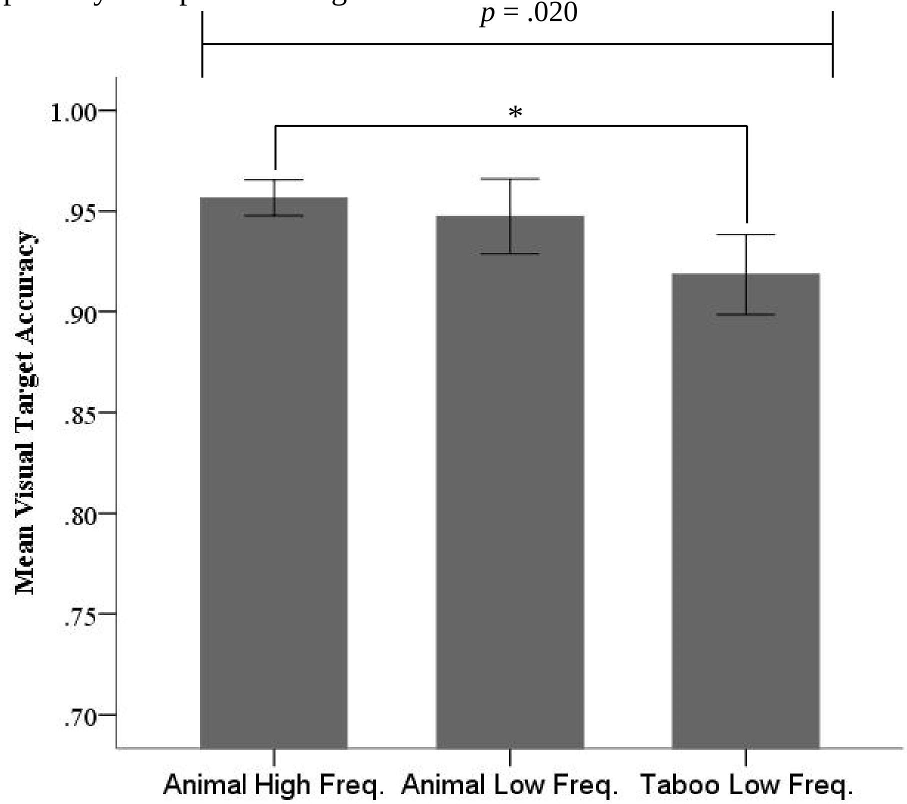

Figure 2-2b. Mean digit categorization accuracy as a function of irrelevant spoken word condition. Error bars represent one standard error of the mean.

Discussion

Taken together, the results show that an unexpected semantic change in a to-be-ignored auditory stream can impair both response time and accuracy to identify and categorize visually presented digits, even when the item is not physically deviant relative to other stream items. Therefore, task irrelevant semantic deviation is sufficient to capture attention, at least when the semantic change involves a high arousal taboo word. Note that to recognize that a word is taboo means that one has heard the word and accessed its semantic meaning. When taboo and neutral words are presented randomly and unpredictably as they were here, semantics cannot be accessed for taboo words, but not emotionally neutral words, because one does not know if a word is taboo or not until semantics have been accessed (i.e., semantic processing must precede categorization of neutral or taboo). Therefore, the results suggest that word meaning is accessed for all irrelevant auditory words, and that both perceptual and meaning information is used to assess the potential value of attending to a deviant auditory stimulus in terms of the need to divert attention.

Previous studies have found that semantic analysis of otherwise irrelevant stimuli occurs only after the detection of a physical change (e.g., pitch or timbre) in the auditory scene (Escera et al., 2003; Parmentier, Elsley, Andrés, & Barceló, 2011; Parmentier, Turner, & Perez, 2014; Parmentier, 2008), and/or if the irrelevant stimuli is in some way semantically related to the primary task (Parmentier et al., 2011, 2014; Parmentier, 2008). The pattern of results can be reconciled if one assumes that all irrelevant auditory stimuli are likely processed for semantic information, but that this information does not influence behaviour unless 1) the stimulus is already being attended by virtue of capturing attention as a physical deviant (Escera et al., 2003; Parmentier et al., 2011, 2014; Parmentier, 2008), 2) the stimulus is semantically related to the primary task's attentional or response set (e.g., speaking the words "left" or "right" while classifying visual digits as pointing left or right; Parmentier 2014), or 3) the irrelevant auditory information is emotionally arousing. In this manner, all stimuli are automatically screened for meaning, but attention is only deployed to a deviant stimulus if its meaning is motivationally relevant (i.e., contextually or emotionally), or if the stimulus is also physically novel.

Experiment 2 is the first to demonstrate that a task-unrelated semantic change without a concomitant special physical change[2], unique to the prevailing pattern of stimuli, can be sufficient to capture attention away from a primary and unrelated visual task. This contrasts with

[2] The term "physical change" is meant to represent a deviation from the prevailing state of auditory stimuli. That is, participants build up a mental model for the presented auditory material but remain sensitive to deviations from that model. Imagine a sound sequence in which a series of "beeps" cycle through 200hz, 300hz, 400hz, and back. Although each beep is physically different from the last, a mental model would be quickly built to include all those tones. If, on a rare occasion, an 800hz tone were played, it would stand out as deviant from the prevailing set of possible tones.

the conclusions of others (Escera et al., 2003; Näätänen, 1992; Parmentier, 2008; Wetzel & Schröger, 2007) who posited that a physical change in the irrelevant auditory stimulus was a necessary antecedent for semantic processing. However, the present results and conclusions are consistent with the recent theorizing of Parmentier et al. (2014) who observed a semantic congruency effect even under conditions of no novelty effect, and concluded that semantic processing of auditory deviants reflects two sources, one of which is dependent on prior attention capture as a deviant, and one which is not.

Additionally, semantic change detection in our experiment produced costs in both RT and accuracy. This pattern suggests that when participants are captured by an unexpected high arousal semantic change, some participants or trials may show accuracy costs whereas other may show response time costs. This may depend on individual difference factors or cognitive processing styles wherein some participants prioritize speed over accuracy or vice versa and are willing to sacrifice one or the other in order to process the unexpected auditory change or on the relative timing of visual versus auditory processing on a given trial.

Previous studies have shown evidence for attention capture leading to reduced performance on a primary visual task when high arousal taboo words were presented visually (e.g., Arnell et al., 2007 in RSVP, MacKay et al., 2004 in a Stroop task, and Aquino & Arnell, 2007 in a digit parity task). For example, MacKay et al. (2004) found increased colour naming times for arousing taboo words relative to emotionally neutral words in a modified Stroop paradigm, and Aquino and Arnell (2007) found that arousing sexual/taboo words slowed digit parity RTs relative to school-related, neutral or threat words when the task-irrelevant word was presented between the two digits. The current study extends the literature, showing that irrelevant arousing sexual/taboo words can capture visual attention at the expense of performance on a visual task even when the arousing words are presented auditorily and the primary task is visual.

The common, and in many cases tacit, assumption that semantic processing is only performed for items that are already attended has its roots in some of the earliest work on selective attention. Broadbent (1958) proposed one of the first influential models of selective attention in which relevant information is distinguished from irrelevant information according to its physical properties (e.g., loudness, pitch, or timbre) before any information is semantically processed. This early selection model was supported by results from dichotic listening tasks in which participants were unable to detect semantic changes in the unattended ear but were able to detect the physical properties of the voice (e.g., whether the voice was male or female, pacing, or how loud it was; e.g., Broadbent, 1958; Cherry, 1953). However, later studies found that semantically relevant stimuli such as one's own name (Moray, 1959; Wood & Cowan, 1995), contextually relevant items (Treisman, 1964), and aversively conditioned words (Corteen & Wood, 1972) could sometimes bypass the acoustic filter mechanism and breakthrough from the unattended ear. Note that the move from purely early selection models to later models that allowed for semantic processing of unselected information in the dichotic listening studies of the 1950s and 1960s parallels the move in the cross-modal oddball literature with respect to semantic deviants.

One difference is that Ljungberg et al. (2014) recently observed that auditory presentations of one's own name did not increase RTs in a cross-modal oddball task. Ljungberg and colleagues tested for an oddball distraction effect using the participants' own names, a matched control name, or non-name words, as infrequent novels presented amongst standard sine wave tones. The detection of one's own name led to extended response times compared to the standard sine wave tone in a digit categorization task. However, the response time cost was not significantly different from the cost associated with the detection of any name or any word. Thus, the effect observed appears to have been driven by the detection of lexicality rather than the semantic content per se. Note, however, that one's own name was both semantically deviant and physically deviant in the Ljungberg et al. study. Thus, attention was already diverted to own or other names given the physical novelty. Therefore, their results cannot answer whether one's own name would capture attention and impair visual task performance in a situation where it was not also physically deviant.

Taken together, these findings extend the current literature in terms of what constitutes a novel deviant. Unexpected semantic change is sufficient to produce a deviance distraction effect and an accompanying physical/acoustic change is not required to induce semantic processing of task-irrelevant stimuli even when the semantic deviants are unrelated to the response set for the primary task.

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Appendix

Animal Words	Non-animal Words	Taboo Words
DOG	BRAIN	BITCH
LAMB	FORK	BOOBS
SWAN	COURT	BREAST
LION	CUP	FUCK
WORM	COIN	GAY
COW	DANCE	LEWD
CAT	ROCK	LUST
PIG	SHOE	PISS
HAWK	BOOK	SHIT
GOAT	FENCE	SLUT
SHEEP	CHAIR	TITS
SKUNK	BAND	WHORE
HEN	CAR	RAPE
MOUSE	SALT	DICK
MOOSE	DESK	FAG
SNAKE	BLOCK	CUNT
FOX	GRILL	CLIT
HORSE	WALL	JIZZ
BIRD	TOWN	SKANK
TOAD	DOOR	TWAT
FISH		
WHALE		
GOOSE		
CROW		
SHARK		
WOLF		
SNAIL		
FROG		

Chapter 3

Non-contingent and contingent attention capture are reliable but not generalizable: An individual differences study

Introduction

Successful daily functioning requires the effective and efficient allocation of limited attentional resources to the selective processing of goal-relevant or subjectively meaningful material out of an almost immeasurable amount of visual input. Sometimes, a non-target stimulus can capture our attention and affect the time it takes to detect a target, typically resulting in impaired target accuracy and/or response times. The present study examines such involuntary attention capture.

There are two theoretical viewpoints on what drives this form of capture. One perspective argues for involuntary capture by stimulus salience in its purest form. That is, any stimulus that is sufficiently salient, such as an abrupt onset/offset, flash, or colour singleton captures attention (at least initially) regardless of the nature of the task, the to-be-attended target, or the viewer's intentions (Burnham, 2007; Hickey, McDonald, & Theeuwes, 2006; Rauschenberger, 2003; Schreij, Theeuwes, & Olivers, 2010; Theeuwes, 1991, 1992, 1994, 2010; Yantis & Jonides, 1984). For example, task-irrelevant abrupt onset stimuli are known to involuntarily capture attention even when they never predict target location (Remington, Johnston, & Yantis, 1992). According to this viewpoint, attention capture by a stimulus is not contingent on that stimulus matching the individual's search set, and it has therefore come to be known as non-contingent capture (e.g., Theeuwes, 1994).

This viewpoint was disputed by Folk and colleagues (Folk, Remington, & Johnston, 1992; see also Gibson & Kelsey, 1998) who found that abrupt onsets would only capture attention if the viewer was also looking for targets that were defined by an abrupt onset. This contrasting contingent attentional capture viewpoint (see also Yantis & Jonides, 1984, 1990) suggests that attention capture is not driven by stimulus salience alone but instead depends also on the individual’s search set parameters. That is, the likelihood of capture by a task-irrelevant stimulus will depend largely on the match between that stimulus and the stimulus-defining features that comprise an individual’s search set. For example, when a participant is looking for a green circle, other green objects in the search array are more likely to be processed and subsequently capture attention. According to this viewpoint capture by a stimulus is contingent on that stimulus matching some parameter of the individual’s search set, and it has therefore come to be known as contingent capture (e.g., Folk et al., 1992).

Despite the large number of studies investigating both non-contingent and contingent attention capture, there have been few studies that have attempted to understand attention capture by examining individual differences in attention capture. A small number of studies have investigated measures that predict one’s tendency to be captured by task-irrelevant stimuli within a single capture paradigm. One measure that has been used successfully is working memory capacity which is thought to underlie a wide range of complex cognitive abilities and executive functions like reading, problem solving, and fluid intelligence (Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2002, 2003). Conway, Cowan and Bunting (2001) used the classic cocktail party phenomenon of Moray (1959) and showed that individuals with relatively low working memory capacity, (as measured by the Operation Span task of Turner and Engle (1989) which measures the ability to hold items in memory while vocally stating and managing distracting material), are more likely to detect their own name in an auditory message played in the task-irrelevant ear. This finding provides evidence that those with low working memory have a reduced ability to inhibit or ignore task-irrelevant distracting material. A similar pattern has been observed in the visual domain where individuals with relatively low visual working memory capacity (as estimated using the Luck and Vogel, 1997 paradigm) show relatively poor filtering efficiency by allowing more task-irrelevant items into visual working memory than those with higher visual working memory capacity (e.g., Arnell & Stubitz, 2010; Vogel, McCollough, & Machizawa, 2005). The finding that the tendency to be captured by, or the inability to resist processing of, irrelevant stimuli is related to working memory suggests that there may be common variance shared between attention capture measures and a more general attentional control factor that varies reliably across individuals.

The use of individual differences studies to look for general attention abilities is relatively new. Two recent studies (Huang, Mo, & Li, 2012; Skogsberg, Grabowecky, Wilt, Revelle, & Street, 2012) have looked for general attention factors across a variety of common attention paradigms such as visual search and multiple object tracking (Pylyshyn & Storm, 1988). Although performance measures were at best modestly correlated across tasks in both studies, Huang et al. (2012) reported a general attention factor underlying task performance across their tasks and described this factor as a flexible, task-agnostic, resource that can be used in various paradigms. Skogsberg et al. (2015) reported that individual attention performance across tasks could be organized along two dimensions: one that contrasts spatiotemporal versus global attention, and another dimension that contrasts transient versus sustained attention.

Neither of the above studies included attention capture tasks, but Kawahara and Kihara (2011) examined individual differences in attention capture using two capture tasks and also measured performance on an attentional blink (Raymond, Shapiro, & Arnell, 1992) task. In the temporal search task, participants were asked to report the identity of a coloured letter target embedded in a rapid serial visual presentation (RSVP) stream that sometimes had irrelevant coloured hashtags presented prior to the target (Folk, Leber, & Egeth, 2002). In the spatial search task, participants were asked to search for a shape in a visual search display that contained an irrelevant novel colour singleton (Theeuwes, 1994). Note that these tasks are similar to the temporal visual search and the non-contingent spatial visual search tasks used here. Interestingly, Kawahara and Kihara observed no correlation between performance on any of the tasks, arguing for separable underlying cognitive processes.

The lack of correlation between the two attention capture tasks in Kawahara and Kihara (2011) may be due to the fact that one capture task was contingent (the colours of the hashtag distractors were the same as those that defined the target in the RSVP temporal capture task) and the other was non-contingent (the singleton was defined by a novel colour that was not part of the target search set in the spatial visual search task). The lack of relationship could also be due to paradigm differences inherent in temporal versus spatial search, or to the fact that targets and irrelevant distractors were separated temporally in one paradigm but only spatially in the other. Use of only two capture tasks makes it difficult to discern possible reasons for the null correlation. Also, although the tasks showed good split-half reliability within the single session studies of Kawahara and Kihara (2011), identifying a general attention capture factor, or lack thereof, also requires that the tasks show trait-like consistency across different sessions to avoid the possibility that state-like factors such as sleepiness, hunger, or caffeine consumption underlie possible relationships amongst tasks.

Here, we examine the reliability and generalisability of attention capture using six different prototypical visual attention capture measures from three different paradigms, thereby providing more opportunities to find commonalities in capture. Participants performed contingent and non-contingent versions of the spatial visual search task (e.g., Theeuwes, 1994), the temporal visual search task (Folk et al., 2002) and the involuntary spatial orienting task (Folk, Remington, & Johnston, 1992). Participants performed each of these tasks twice one week apart providing the unique opportunity to examine test-retest reliability which speaks to the stability of attention capture for a given individual over time within the same task. The current study could produce several potential outcomes in terms of reliability and generalizability. Previous research has been limited largely to tests of within-session reliability. Thus, it cannot be known whether such reliability is due to a stable individual trait or whether it could be explained by state effects. If capture is trait-like in nature then test-retest reliability should be high, reflecting stable individual differences between sessions. In terms of generalizability, several outcomes are possible. First, it may be the case that capture in each of the tasks is driven by a common general attention factor. In this case, we would expect positive correlations between all measures of capture in each task. Secondly, we may expect positive correlations only between capture scores derived from the same task (two scores from the temporal visual search tasks) or paradigm (e.g., the two versions of the spatial search tasks). A third possibility is that measures of contingent capture may correlate with each other, and measures of non-contingent capture may correlate with each other, but measures of contingent capture may not be related to measures of non-contingent capture. Alternatively, a fourth possibility is that we may find that capture is unrelated between tasks. This outcome would implicate other, more subtle, differences in task parameters as a source of variation in capture scores.

Methods

Participants & Apparatus

One-hundred and thirty-five undergraduate students (113 female) at Brock University participated in exchange for research credit hours for a course. Mean age was 19.12 years with a range of 18 to 28 years of age. All participants reported normal or corrected-to-normal visual acuity and no colour blindness. Only 70 participants performed the Non-Contingent Spatial

Search task which was added part way through the study.[3] The study received ethics clearance from the Brock University Research Ethics Board.

Design

All experimental stimuli were presented via a Dell desktop computer running E-Prime (v1.1; Schneider, Eschman, & Zuccolotto, 2002) and responses were made using the Dell desktop computer keyboard. Each experimental session contained four computer-based attention tasks which participants completed in the following order: 1) Temporal Visual Search, 2) Non-contingent Spatial Visual Search, 3) Involuntary Spatial Orienting, 4) Contingent Spatial Visual Search, each described below.[4] Each participant completed two sessions separated by one week. For a given participant, each session took place at the same time of day and tasks were completed in the same order on both days. In this way, capture reliability could be calculated for each attention task both within a given session and between sessions (test-retest reliability).

Temporal Visual Search

Parameters for the Temporal Visual Search task were based on the task as described in Folk et al. (2002). Stimuli were randomly selected and individually presented letters (excluding I, O, Q, and Z). All letters were presented in upper-case in the centre of the screen in 36-point gray Courier font on a black background using a 17-in. CRT monitor with a refresh rate of 75 Hz. Visual stimuli were approximately 9 mm high by 9 mm wide. From an unfixed viewing

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[3] Mean comparisons and correlations involving the other capture tasks revealed the same general pattern of results overall irrespective of whether 70 participants or all 135 participants were included. However, all participants were retained for the purpose of developing a clearer picture of the relationship between capture measures.

[4] All participants completed the capture tasks in the same order, so that estimates of participants' attention capture sizes would not be confounded with task order. When conducting an individual-differences study, it is not ideal to counterbalance the tasks across participants, as performance on tasks/blocks may differ somewhat because of the order in which they are presented, thereby confounding capture scores with order variability. This confound can be removed in individual-differences studies by using a constant task order as we did here.

distance of 50cm, each stimulus subtended approximately 1.0° of visual angle in height and width. See Panel A of Figure 3-1.

Each trial began with the presentation of a white fixation cross presented centrally for 500ms and subtending a visual angle of 0.8° in height and width, followed by a 200ms blank inter-stimulus interval. Following the blank interval, 20 letters were randomly selected (without replacement) and individually presented in the centre of the screen at a rate of 10 letters per second (100ms per item with no blank inter-stimulus interval). All letters were presented in a gray font with the exception of one target letter which was presented equally often in blue, yellow, green, or red font. The number of gray letters preceding a target letter varied from 11 to 15 and was determined randomly for each trial. On distractor trials, a set of 4 hashtags (#), each presented 4.5° above, below, left, and right of a non-target letter, was displayed for 100ms and coincided with the presentation of the non-target letter appearing two positions (200ms) before the target letter. Each hashtag subtended a visual angle of approximately 0.8° in height and width. Four distractor conditions were used. Under the same-colour condition, three of the hashtags were gray and one of the hashtags was presented in the same colour as the yet-to-be-seen target letter. Under the different-colour condition, three of the hashtags were presented in gray and one was presented in a different colour from the yet-to-be-seen target letter. In the all-gray condition, all four hashtags were presented in gray. In the no-distractor condition, no hashtags were presented.

A within-subject design was employed such that each participant was exposed to all four distractor conditions. Participants viewed 20 trials of each distractor condition for a total of 80 trials. Distractor type was intermixed throughout the task. Participants did not know the colour of the target letter at the start of each trial, and therefore instructions asked them to report the identity of the odd-coloured letter (e.g., the only coloured letter amongst a stream of gray letters) at the end of each stream with a key press. Responses were unspeeded and accuracy was scored.

Target letters were always defined as the only coloured letter amongst a series of gray letters. Hashtag distractors could be defined in two ways: by presence/absence and by colour. Thus, capture in this task can be described in two ways: Non-Contingent and Contingent. In the case of non-contingent capture, the features of the target and the distractor do not match. That is, the target odd-coloured letter is defined by its colour whereas the distractor is defined only by its presence (e.g., the all gray condition). Capture in this case is produced predominately by exogenous sources whereby the processing of a non-specific distractor reduces target identification accuracy. This form of capture is shown in higher mean accuracy in the distractor-absent condition than in the all gray distractor condition. In the case of contingent capture, the feature of colour is shared between distractor hashtags and target odd-coloured letters. Given that targets are defined by their colour, distractors that are also differentiated by colour should reduce target identification accuracy to the extent that the feature of colour is being used as a target detection parameter. In this way, hashtag distractor processing is contingent on the use of colour as a search feature. Contingent capture is shown by higher mean accuracy in the all gray distractor condition than the mean of same- and different-colour distractor conditions. Capture was not expected to differ as a function of same/different colour distractor condition as the participant is always unaware of what colour the odd-coloured target letter will be until it is actually presented.

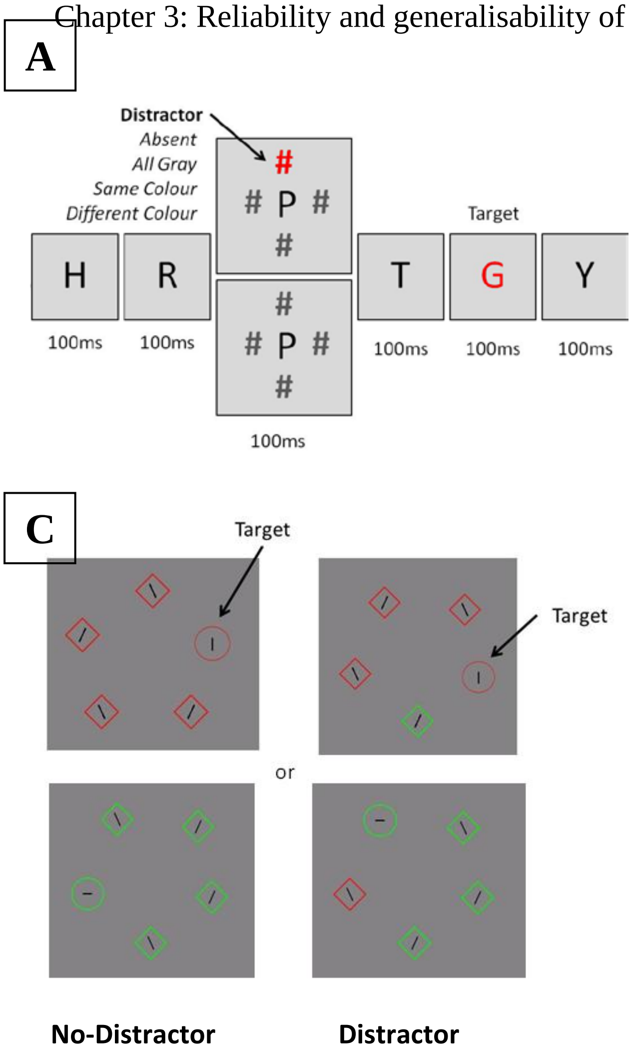

Figure 3-1. Illustration of stimuli from each task. Panel A shows a representation of stimuli in two of the four conditions (same colour and all gray) of the Temporal Visual Search task. Note that participants viewed letters in a gray font on a black background. Panel B shows stimuli from the Contingent Visual Search task. Panel C shows stimuli from the Non-Contingent Visual Search task. Panel D shows an illustration of stimuli from the invalid onset and invalid colour conditions of the Involuntary Spatial Orienting task. Note that participants viewed gray boxes on a black background.

Contingent Spatial Visual Search

Parameters for both Spatial Visual Search tasks were based on the task as described in Theeuwes (1994). Stimuli were comprised of 5 or 7 items presented in a circular array displayed in the centre of the screen. The diameter of this invisible circle subtended 6.4° of visual angle. Target stimuli were vertical and horizontal lines (0.7° of visual angle) contained inside a circle subtending 1.6° of visual angle. Non-target stimuli were comprised of black lines (0.7° of visual angle) rotated 22.5° from vertical or horizontal contained within a square subtending 1.6° of visual angle. See Panel B of Figure 3-1 for an illustration of stimuli.

Each trial began with the presentation of a small black fixation dot in the centre of screen subtending a visual angle of 0.3° presented for 250ms. This dot then expanded to 0.6° of visual angle for 600ms to warn participants and then contracted back to 0.3° of visual angle for a jittered duration (100ms, 200ms, 400ms, 600ms, 800ms, or 1000ms determined randomly on each trial). Following a 300ms blank ISI, the search array was presented in which one target and 4 or 6 non-target items were displayed. This array remained on screen until participants indicated whether the target line was vertical or horizontal with a key press as quickly and as accurately as possible. Target location in the array was determined randomly for each trial. Following participants' response a blank ISI (jittered as above) preceded the onset of the fixation dot for the next trial.

In the contingent spatial search task, target lines were always presented inside a green circle and non-targets were always presented inside squares. In the no-distractor condition (half of trials), all non-targets were presented in red squares; in the distractor condition (half of trials), one of the non-targets, selected at random, was contained inside a green square. All stimuli were presented against a gray background. Distractor and no-distractor trials were equally distributed among set sizes of 5 and 7. All trials were intermixed within a given experimental block.

In this task, targets were defined as always being contained inside a green circle. Thus, targets presented amongst an array of red squares were expected to be relatively easy to detect and identify. In contrast, targets presented in the distractor condition, that included a single green square, should be more difficult to detect and identify quickly as the feature green, being target-relevant, is now also found in a distractor. In addition to the feature of shape, the search feature of green is a filtering strategy that would be highly effective on non-distractor trials, thus, non-target items that share this feature with targets may be more likely to capture attention. Note that capture in this task is contingent only to the extent to which an attentional set for the colour green has been developed. Capture in this task is shown as a longer response time (RT) mean for the distractor-present than the no-distractor condition.

Non-Contingent Spatial Visual Search

All stimuli and timing were identical to the Contingent Visual Search task described above, but with one critical difference. Participants were instructed that black target lines (vertical or horizontal) would appear inside a circle regardless of the circle's colour. That is, targets could appear inside a red circle or inside a green circle (equally often). Distractor items were always squares. On no-distractor trials, all of the squares were the same colour as the target. On distractor trials, one of the squares was presented in a different colour (red or green) from the target and other distractors. See Panel C of Figure 3-1 for an illustration.

Because targets were defined as always being contained inside a circle, target colour changed unpredictably trial to trial, and targets and distractors were shown in the same colour, only container shape (e.g., square versus circle) could be used as a reliable search filter. In this way, distractors shared no features with the search set —capture by distractors was not contingent on the attentional set for circle. Therefore, capture by non-target colour singletons reflects unnecessary processing of irrelevant colour content and is non-contingent. Capture in this task is shown by the longer RT for the distractor present condition compared to the no-distractor condition.

Involuntary Spatial Orienting

The stimuli and procedure for this task were based on the involuntary orienting task of Folk and colleagues (Folk et al., 1992). Stimuli were comprised of a set of 5 gray boxes, each subtending 2.0° of visual angle in height and width, arranged in a cross and presented centrally on a black background. See Panel D of Figure 3-1. Targets were the letter X and an equal sign (=), each subtending a visual angle of 0.7°, presented in a white font.

Each trial began with a fixation of 5 empty boxes. After a jittered amount of time (1000 – 1400ms) the fixation was replaced with a cue which remained on the screen for 50ms. Then following a 100ms interval displaying only the empty boxes, the target appeared in one of the four surrounding boxes. Participants were required to categorize the target as the letter X or an equal sign as quickly and as accurately as possible. Targets appeared in only one of the four surrounding boxes (never the centre box). Cues could be of two types. In the onset cue condition, one of the four surrounding boxes was illuminated white while the three remaining boxes stayed gray. In the colour cue condition, all four boxes illuminated; three locations turned white and one location turned red. For both types of cues, the location of the cue could be valid (matched with location of target) or invalid (did not match the location of the target). The cues were valid on 25% of trials and therefore did not predict the location of the subsequent target.

Targets were always defined by the rapid onset of the “X” or “=” (e.g., their sudden appearance). Based on the previous findings of Folk et al. (1992), capture in this involuntary orienting paradigm is expected only under conditions where distractors match a feature of the target. In this task, only the onset cue condition shares a feature with onset targets; colour cues do not match the attentional set for the target. Thus, capture by onset cues is contingent on the development of an attentional set for onset features, and capture by onset cues, but not colour cues, is expected. For both onset and colour cues, capture would be shown if there were longer RTs for invalidly cued trials than for validly cued trials.

Results and Discussion

For the spatial visual search and involuntary spatial orienting tasks where RT was the dependent variable, RTs were included in analyses only for correct target identifications. Individual participant RTs were also subjected to a single pass, non-recursive, outlier removal procedure that removed RTs that fell beyond +/- 3 Standard Deviations from their individual mean RTs in each condition. For all six capture measures, the expected pattern of means was found in each experimental session. Data presented in figures and results are collapsed across both experimental sessions showing the grand mean in each condition averaging across participant and session. All differences found to be statistically significant across sessions were also found to be statistically significant within each experimental session.

Capture costs are often discussed as if they were differences (e.g., the difference of accuracy in a distractor condition from the accuracy in a no-distractor condition). However, for the purpose of statistical analyses of test-retest reliability and inter-correlations, standardized residual scores are used instead. To create these residuals, for each task, performance in the no distractor condition was used to predict performance in the comparable distractor condition, and the remaining (residual) variability was standardized and saved to be used as the measure of capture for each individual (e.g., how much longer was the distractor RT for that person compared to what we would have predicted using the no-distractor RT). Residuals are preferable to difference scores in that they control for baseline performance differences between participants (see DeGutis, Wilmer, Mercado, & Cohan, 2013 for a demonstration of the superiority of residuals and more thorough discussion of this issue). Furthermore, the use of standardized residuals makes a comparison of accuracy-based costs and RT-based costs more intuitive. Additionally, in the Temporal Visual Search task, the use of residuals is preferable given that the subtrahend in the difference score determining non-contingent capture is the minuend of the difference score determining contingent capture. Calculating residuals for each capture measure alleviates this mathematical issue which could cause spurious correlations between the two temporal visual search capture estimates. Despite the superiority of residual measures, and the fact that they can sometimes produce very different estimates from difference scores, in this case the capture costs calculated as residuals are highly correlated with costs calculated as a difference score in each of the tasks described below (all *r*s > .96, *p*s < .001), and therefore all of the patterns reported below were also observed when difference scores were used.

Temporal Visual Search

Means Comparisons. Mean target accuracy scores were submitted to an ANOVA in which distractor condition (none, gray, different colour, same colour) was entered as a within-subjects factor. See Figure 3-2A for means. Overall, results indicated a significant main effect of distractor condition, $F(3, 402) = 225.01$ $p < .001$, $\eta^2 = .623$. Follow-up paired-samples t-tests indicated that all pairs of means were significantly different from each other, all *p*s < .001. These results indicate that both contingent and non-contingent attention capture occurred in this task as expected.

Reliability. Non-contingent cost was calculated as accuracy in the All Gray condition controlling for accuracy in the No-Distractor condition. Contingent colour cost was calculated as the mean accuracy of the same- and different-colour distractor conditions controlling for accuracy in the All Gray condition. Results showed good test-retest reliability over one week for non-contingent capture by onset distractors (all gray controlling for no distractor), *rr* = .67, $p <$ .001 and for contingent capture by colour distractors (mean of same/different colour controlling for gray), *rr* = .49, $p < .001$. See Figure 3-3A for scatterplots of these relationships.

Contingent Spatial Search

Means Comparisons. RTs were submitted to a paired-samples t-test in which distractor condition was a within-subjects factor. See Figure 3-2B for means. Results indicated a significant effect of distractor condition where RTs were significantly longer when the distractor was present versus absent, $t(134) = 15.60$, $p < .001$, $d = .40$, demonstrating that the expected attention capture occurred in this task.

Reliability. Capture cost was calculated as RT in the distractor condition controlling for RT in the no distractor condition. Results showed significant test-retest reliability over one week for contingent capture by distractors, *rr* = .41, $p < .001$. See Figure 3-3B for a scatterplot of this relationship.

Non-Contingent Spatial Search

Mean Differences. RTs were submitted to a paired-samples t-test where distractor condition was a within-subjects factor. See Figure 3-2C for means. Results indicated a significant effect of distractor condition, $t(69) = 9.26$, $p < .001$, $d = .45$, where RTs were longer for the distractor condition compared to the no distractor condition, indicating the presence of attention capture in this task.

Reliability. Capture cost was calculated as RT in the distractor condition controlling for RT in the no distractor condition. Results showed good test-retest reliability over one week for non-contingent capture by distractors, *rr* = .54, $p < .001$. See Figure 3-3C for a scatterplot of this relationship.

Involuntary Spatial Orienting

Mean Comparisons. RTs were submitted to an ANOVA in which cue type (onset vs. colour) and cue validity (valid vs. invalid) were entered as within-subjects factors. See Figure 3-2D for means. Overall, results indicated a significant main effect of cue validity, $F(1, 134) = 55.54$, $p < .001$, $\eta^2 = .293$ but no main effect of cue type, $F(1, 134) = .19$, $p = .659$, $\eta^2 = .001$. Importantly, a significant interaction between cue validity and cue type was observed, $F(1, 134) = 63.33$, $p < .001$, $\eta^2 = .321$. Follow-up t-tests performed separately for each cue type indicated that capture occurred for onset cues (valid vs invalid), $t(134) = 9.83$, $p < .001$, $d = .50$, but not for colour cues (valid vs. invalid): $t(134) = 0.88$, $p = .381$, $d = .04$, replicating the pattern of results observed by Folk et al. (1992) where capture in this task occurred only when distractors shared at least one feature with the target.

Reliability. For the onset cue condition, capture cost was calculated as RT in the invalid cue condition controlling for RT in the valid cue condition. Results showed significant test-retest reliability over one week for contingent capture, $rr = .40$, $p < .001$. See Figure 3-3D for a scatterplot of this estimate. Reliability estimates were not examined for colour cues as this condition did not show significant capture overall or in either session.

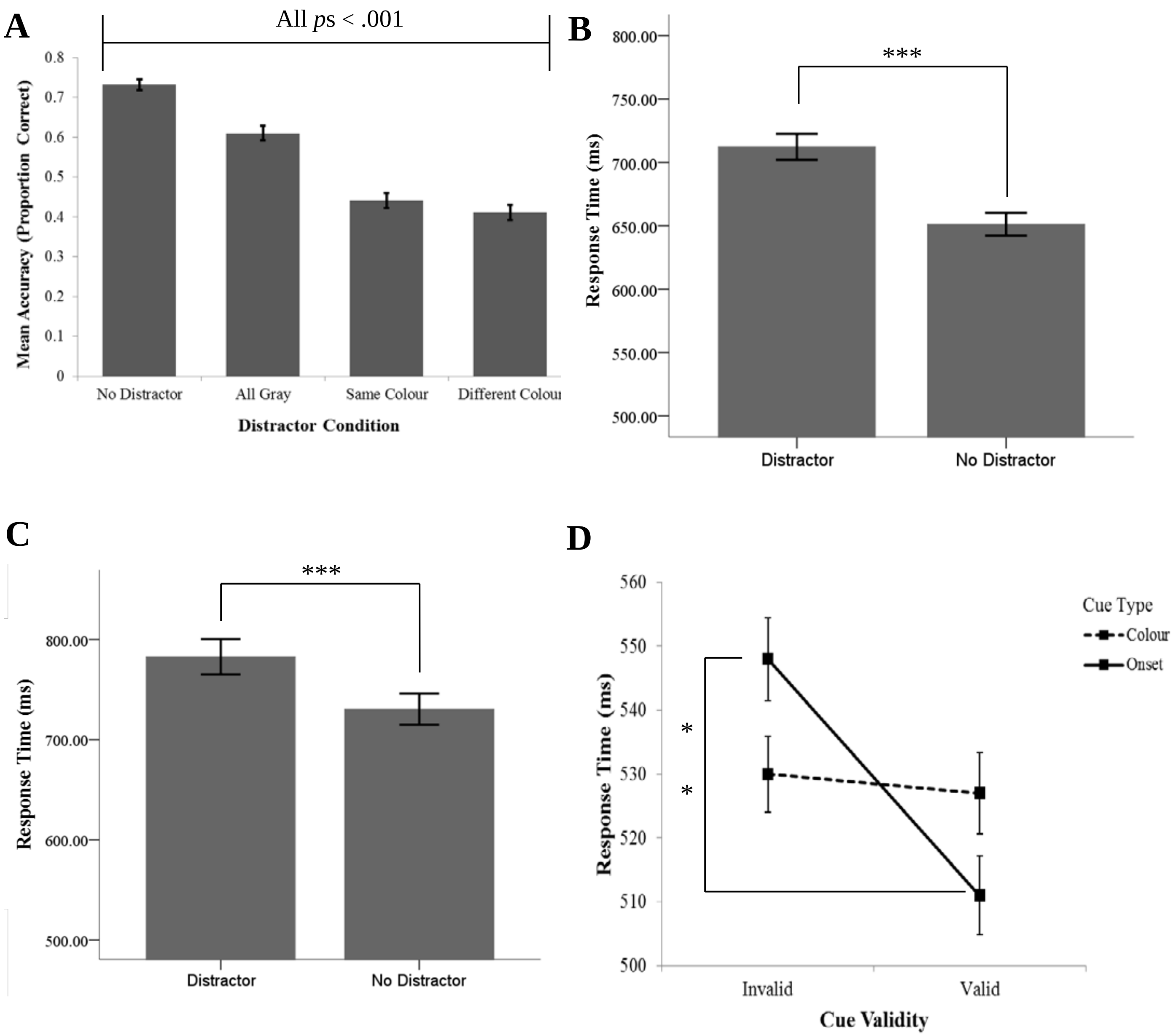

Figure 3-2. Dependent variable means from each of the capture tasks. In all cases error bars represent +/- 1 standard error of the mean. Panel A shows mean target identification accuracy as a function of distractor condition in the temporal visual search task. Non-contingent cost is the difference between the No Distractor and the All Gray conditions; Contingent cost is the difference between the All Gray condition and the mean of the two colour conditions. Panel B shows mean correct-identification response times as a function of the distractor presence in the Contingent Visual Search task. Panel C shows mean correct-identification response times as a function of the distractor presence in the Non-Contingent Visual Search task. Panel D shows the results from the Involuntary Spatial Orienting task: Mean correct-identification response times as a function of the cue validity (horizontal axis) and cue type (separate lines). Analyses indicate statistically significant capture for contingent (onset) cues, but not non-contingent (colour) cues.

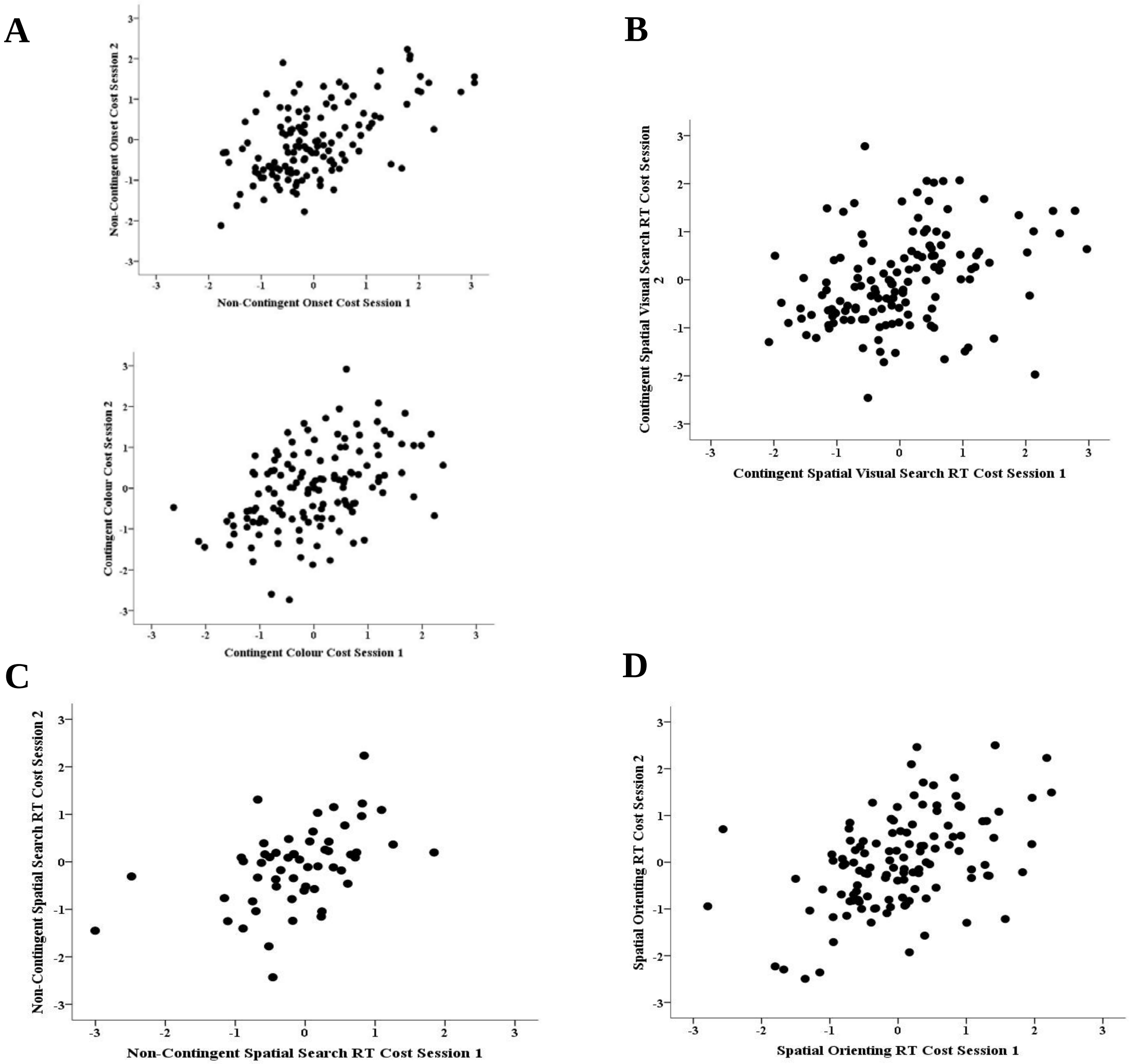

Figure 3-3. Scatterplots of test-retest reliability for each attention capture measure, expressed in standardized residuals where greater positive values reflect greater attention capture. Horizontal axes show capture costs from session 1; vertical axes show capture costs from session 2 completed one week later. Panel A shows reliability of two forms of attention capture in the Temporal Visual Search task. The top plot shows non-contingent onset costs ($rr = .67$, $p < .001$); the lower plot shows contingent colour costs ($rr = .49$, $p < .001$) expressed as standardized residuals. Panel B shows reliability ($rr = .41$, $p < .001$) for Contingent Spatial Visual Search. Panel C shows reliability ($rr = .59$, $p < .001$) for Non-Contingent Spatial Visual Search. Panel D shows the test-retest reliability ($rr = .40$, $p < .001$) for capture by onset cues in the Contingent Involuntary Spatial Orienting task.

Reliability and Intercorrelations Between Capture Tasks

The present study is the first to examine test-retest reliability of, and inter-correlations amongst, several commonly used attention capture tasks with sessions spaced days apart. In a relatively large sample, capture was found to be reliable and stable within individuals over the span of one week for all five significant measures of attention capture, with test-retest correlations between .40 and .67. Indeed, when internal-consistency reliability of the 5 capture measures was estimated within a given session with a split-half method using odd and even trials, and a Spearman–Brown correction was applied (Nunnally, 1978), within-session reliability approximated between-session reliability with within-session reliability estimates of .79, .67, .60, .52, and .45 for non-contingent temporal search, contingent temporal search, non-contingent visual search, contingent visual search and involuntary spatial orienting respectively. These within session reliability estimates are also consistent with those of Kawahara and Kihara (2011) who showed within session odd/even trial correlations of .74 for temporal visual search and .56 in non-contingent spatial visual search from their single-session study.

Finding roughly equivalent reliability between and across testing sessions separated by one week provides evidence that attention capture was not influenced by random state factors such as arousal, fatigue, sleepiness, state affect, concern with finishing on-time and other situational contributors. The present findings suggest that within a given attention capture task, individuals vary in a trait-like manner in their susceptibility to capture by distractors that both match and do not match the current target-relevant attentional set.

Knowing that individual differences in attention capture are relatively stable over time within attention capture tasks, one can then examine correlations between capture tasks to see if individuals vary in their propensity to have their attention captured generally or whether this is task or paradigm specific. It is possible that measures of capture could be driven by a common underlying factor so that an individual's tendency to be captured by irrelevant stimuli in one task would be related to the magnitude of capture in another task. If so, then one would expect to observe positive correlations between the cost estimates in each of the attention capture tasks such that those who showed the most capture in one task should show the most capture in another. This was not the case. Table 3-1 provides an overview of the Pearson inter-correlations of capture cost between each of the attention tasks in the present study using the same residual measures of capture used to calculate the test-retest reliability[5][6]. Figure 3-4 shows the scatterplots of these relationships. Measures of capture were unrelated between tasks. That is, capture in one task was not associated with capture in any of the other tasks. Thus, there does not appear to be a common capture factor underlying the attention tasks used here. This finding is concerning as capture tasks are sometimes used in studies interchangeably as if they measure a common source of capture.

Table 3-1

Between-task zero-order correlations of capture costs.

	rr	2	3	4	5
1. Non-Contingent Temporal Search	.67*	.02	-.19	-.16	.08
2. Contingent Temporal Search	.49*	--	-.06	.01	-.08
3. Non-Contingent Spatial Search	.54*		--	.08	.14
4. Contingent Spatial Search	.41*			--	.15
5. Involuntary Spatial Orienting	.40*				--

Note: Correlations based on standardized residual calculations of costs. The column "*rr*" indicates reliability of cost measure.
All *p*-values > .07

[5] Table 3-1 and Figure 3-4 show data averaged across both sessions. This pattern was also observed when analysing data separately within each session.
[6] The same analysis was conducted using Spearman Rho to examine the possibility that a participant's relative ranking of capture was related between tasks. This was not the case. The relative ranking of capture magnitude was not correlated between tasks. The same null pattern of results was also observed when Intra-Class Correlations were run, suggesting little agreement between capture tasks.

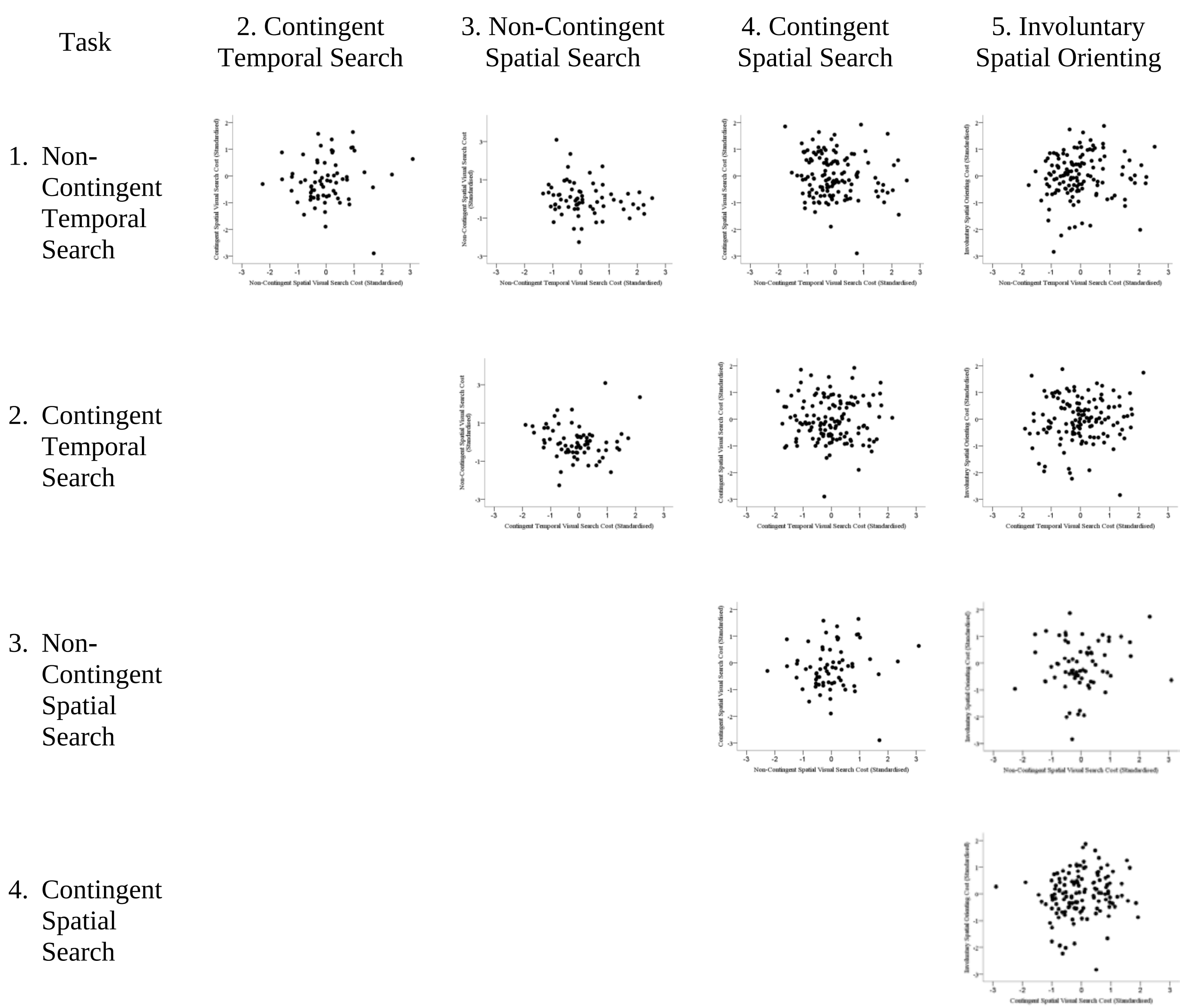

Figure 3-4. Scatterplots of between-task zero-order correlations of capture costs. Scatterplots are arranged in the same order as in Table 3-1. The horizontal axis in each scatterplot represents the rows; the vertical axis in each scatterplot represents the columns. None of the relationships are significant.

The absence of intercorrelations cannot be attributed to a lack of power as 135 participants were tested in the present experiment and the use of residuals helps to diminish any possibility that the lack of intercorrelations was due to baseline performance differences which could afford different opportunities for larger difference scores for some individuals on some tasks. Indeed, the same pattern of null correlations amongst tasks was observed when difference scores were used to measure capture. Similarly, the absence of associations cannot be attributed to poor reliability of the tasks as test-retest reliability was acceptable for all measures in this study. Thus it would appear that capture in any given task presented here is produced by a trait-like consistency that is highly task-specific. A given individual shows a stable capture cost for each task, but their capture in a given task remains unrelated to capture in another task. What is puzzling is that there would be such a stable mechanism for capture in an individual that is so strikingly unrelated to capture in other tasks performed by the same individual in the same experimental setting.

Presumably the lack of correlation between tasks is due to differences in task parameters. For example, unlike the Spatial Search task, the Temporal Search task presented all stimuli in one spatial location, thus, introducing some between-task variance with respect the need to move attention across spatial locations. Similarly, distractors in the Visual Search task are presented simultaneously with targets, whereas in the Temporal Visual Search and Involuntary Orienting paradigms distractors/cues are presented hundreds of millisecond before the targets, thereby providing a potential opportunity to mitigate their influence to some degree. However, even capture estimates derived from the same task are unrelated (for example, the temporal visual search task provides two measures of capture which are unrelated), therefore any task- or stimulus-dependent processing differences must arise from very subtle differences. However, other evidence here suggests that these differences are not trivially subtle. For example, in the non-contingent Spatial Visual Search tasks, targets were contained in either a red or a green circle and this varied randomly from trial to trial. It is possible that stimulus-dependent processing differences due to variation in target container colour could account for a lack of inter-correlations between capture measures. However, this was not the case, as cost when the target container was red was correlated with cost when the target container was green, $r(70)$ =

.37, $p = .002$ within the task. Furthermore, neither of these cost measures were correlated with any of the other tasks—most notably the Contingent Spatial Visual search tasks where the target container was always green, $r = .14$, $p = .251$ (Green container), $r = .07$, $p = .550$ (Red container). A similar pattern was observed for the same- and different-colour distractor conditions in the Temporal Visual Search task. Cost for the same- and different-colour conditions were highly positively correlated, $r(135) = .69$, $p < .001$, but both remained uncorrelated with other capture measures in the experiment.

One could also have reasonably expected contingent capture estimates to relate to one another but remain independent of non-contingent capture estimates which might in turn be related with one another. However, this was also not the case. Thus, it appears that even subtle changes to task parameters such as the relationship between targets and distractors is enough to alter the nature of capture (e.g., Becker, Folk, & Remington, 2013; Folk, Leber, & Egeth, 2002; Folk et al., 1992; Schoeberl, Fuchs, Theeuwes, & Ansorge, 2014; Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, 1992, 2010).

Kawahara and Kihara (2011) also found a null association between Contingent Temporal Search (defined as the difference between No Distractor and the average of the same/different colour distractor conditions) and the Non-Contingent Spatial Search task (no other attention capture tasks were included in their study). They discuss the possibility that the two types of attentional capture in the temporal and spatial tasks reflect different attention bottlenecks. Specifically, that the capture reflected in the Temporal Visual Search task is driven by a shift of spatial attention away from the central focal point and towards a surrounding distractor hashtag (e.g., Folk et al., 2002) whereas the capture reflected in the Contingent Spatial Search task may be driven by filtering limitations whereby salient task-irrelevant stimuli in the search array are not effectively filtered (Folk & Remington, 1994). However, this distinction alone is unable to account for the lack of correlation between the two Spatial Visual Search tasks or between the two Temporal Visual Search measures used here. Indeed, the use here of both contingent and non-contingent capture tasks in the temporal search, spatial visual search, and involuntary spatial orienting paradigms allows me to rule out explanations that explain null correlations in terms of the difference between temporal versus spatial paradigms or contingent versus non-contingent search.

In line with Gibson and Kelsey's (1998) view (see also Burnham, 2007; Schreij et al., 2010), it is possible that any abrupt onset, regardless of task parameters, would capture attention because essentially all components of the visual display are presented as onsets even when targets are defined by colour. Note, however, that positing that non-contingent onset capture could underlie performance in each task would lead one to predict commonality amongst tasks, yet the present results provide evidence for a lack of shared variability across tasks.

Instead, differences in how targets and distractors are weighted for attention across tasks may drive the null correlations between capture measures yet provide some consistency within a given capture measure over time. Long- and short-term experience with stimuli shapes their significance for attention such that highly salient stimuli associated with reward, fear, or past experience can capture attention even though they do not match current selection goals and are not otherwise physically salient (e.g., Anderson, Laurent, & Yantis, 2011). The valuations that guide attention may be task specific because they work not only on life-long learning, but also within the given context of each task. Different task contexts may therefore lead to different attentional valuations and subsequent attentional weightings for different distractors for different individuals, and within a given task these valuations may be consistent for an individual over time.

Conclusions

Taken together, reliable attention capture was observed across one week for five different measures of capture from three different capture paradigms. However, no evidence was found for a general attention capture factor. Any given measure of capture was unrelated to every other measure of capture. What drives these differences is unclear. Differences in capture do not appear to be constrained by whether the task is contingent or non-contingent or by whether the task is spatial or temporal in structure. Instead, these differences must be subtler than suggested by the tasks' broad categorical label, but not as specific as low-level stimulus properties. Individual differences in stimulus valuations may lead to task- and stimulus-specific attentional and inhibitory weightings that are unique to an individual but consistent within an individual over time. However, regardless of the exact mechanism, these results suggest that it is important to understand what the different attention capture tasks are really measuring. I urge researchers in future studies to be cautious in their selection of attention capture tasks as not all measures of contingent or non-contingent capture are the same—even if they ostensibly all measure attention capture.

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Chapter 4

Attention capture is not predicted by executive control of working memory or self-reported every day attentional control

Introduction

Sorting out relevant information from the wide and diverse scene of stimulation that surrounds us in day-to-day life requires a highly complex, finely tuned, system of cognitive resources. What is known is that individuals vary widely in terms of their ability to perform this daunting task. Salient stimuli such as abrupt onsets or sudden colour changes are known to produce a rapid and involuntary re-allocation of attention to them even if they are irrelevant to task-goals (Hickey, McDonald, & Theeuwes, 2006; Theeuwes, 1991, 1992, 1994, 2010; Yantis & Jonides, 1984). However, the extent to which these stimuli can capture attention is also known to be modulated by top-down goals and attentional settings (Folk, Leber, & Egeth, 2008; Folk, Remington, & Johnston, 1992; Folk & Remington, 1994; Yantis & Jonides, 1984). How stimuli are selected is determined by top-down processes such as task goals and the development of search set parameters. For example, when looking for a green circle, other green shapes may also capture attention as “green” is part of the target search set parameters. The nature of the interaction between top-down attentional setting mechanisms and capture is a matter of debate, but it may be driven at least partly by individual differences in the capacity to develop and maintain effective search strategies. This ability also manifests in daily life as individuals vary widely in terms of day-to-day cognitive functioning and attentional control as reflected in self-report questionnaires such as the Attention Control Scale (ACS; Derryberry & Reed, 2002). One way we can examine the range of individual differences in filtering ability is to look at individual differences in the susceptibility to capture by task-irrelevant material. At the surface, one would expect that individuals who show good performance in laboratory-based attention capture tasks should also yield effective and efficient day-to-day functioning to the extent that the same attentional systems are at play in the lab and in real life.

Studies of attentional control and distractibility can use a range of response-time and accuracy tasks. The tacit assumption in these studies is that the form of attention capture reflected in one task is essentially the same as the form of attention capture reflected in other capture tasks. However, previous demonstrations (see Chapter 3) have shown that these tasks are not universally interchangeable. Capture in one task (e.g., Temporal visual search; Folk, Leber, & Egeth, 2002) has been shown to be unrelated to capture in another task (e.g., Spatial visual search; Theeuwes, 1994) despite the respectable test-retest reliability of each task. Thus, the nature of attention capture and the individual differences therein remains poorly understood. The finding that attention capture is unrelated between two tasks that ostensibly tap the same attentional processes provided the impetus for the present paper. If attention capture cannot be predicted by performance in other computer-based cognition tasks, perhaps it can be explained by variation between how individuals function in day-to-day life. To the extent that day-to-day life requires the efficient deployment of attentional resources over space and time, so should laboratory-based attention tasks that ostensibly require the same mechanisms. Thus, it should be possible to determine a given individual's susceptibility to attention capture and generalize between laboratory and real-world environments.

An important point to make is that attention capture can assume two separable forms. Indeed, current theories that outline the nature of attentional control make the same argument (e.g., Bundesen, 1990; Jonides, 1981; Posner, 1980; Yantis & Jonides, 1984). One form is a voluntary (e.g., endogenous), top-down control of attention that the individual controls directly and consciously to selectively attend to specific stimuli or components of a scene. In this manner, distractors that share features of the target search set may capture attention at the expense of the target (an effect referred to as contingent capture). In contrast, involuntary (e.g., exogenous) bottom-up attention capture is driven by stimulus salience or sudden changes in an attentional scene. Therefore, even stimuli that do not share features with the target may capture attention if they are salient enough (an effect referred to as non-contingent capture). These two forms of attention must strike a balance between maintaining focus on goal-relevant stimuli while remaining open to processing unexpected new or personally salient stimuli (Folk et al., 1992).

In the following two studies, the same set of attention capture tasks as presented in Chapter 3 is used, including Temporal Visual Search (Folk et al., 2002), Contingent and Non-Contingent Spatial Visual Search (Kawahara & Kihara, 2011; Theeuwes, 1992), and Involuntary Spatial Orienting (Folk et al., 1992). For an illustration of each task, see Figure 4-1. Although capture in each of these tasks was reliable over the span of 7-10 days, capture in a given task was unrelated to capture in any of other the other tasks (see Chapter 3). Thus, on-line attention capture does not appear to generalize across tasks. However, one remaining possibility is that alternative off-line measures of attention capture or other attentional abilities may predict capture in one or more of these tasks. If so, then the pattern of relationships observed may inform the nature of attention capture in various paradigms and suggest commonalities across some subset of tasks. This is the primary goal of the current chapter. Study 1 examines the predictive utility of executive control of working memory, self-reported attentional control, and self-reported multitasking habits. Study 2 explores potential predictors of attention capture using a more exhaustive set of self-report measures.

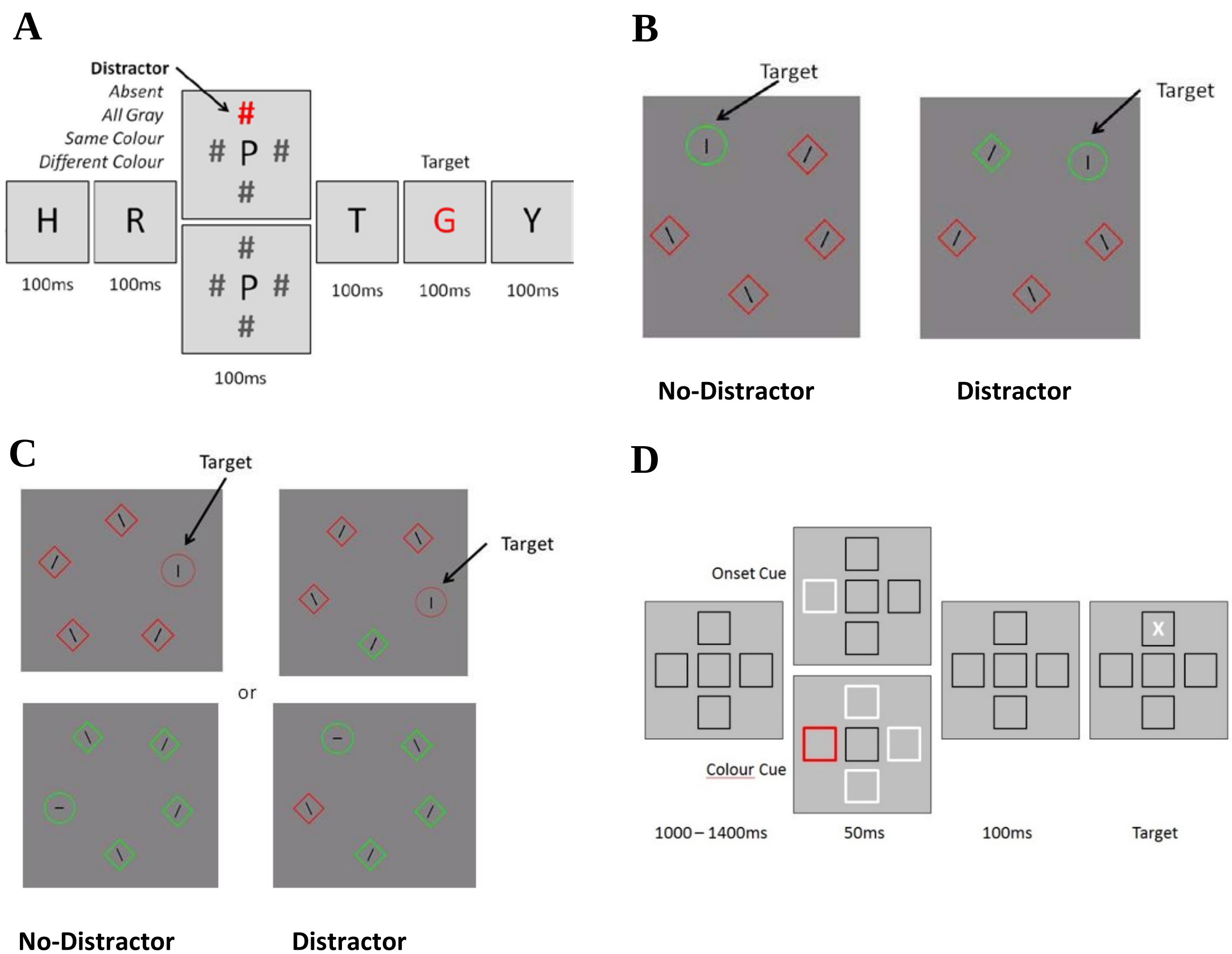

Figure 4-1. Illustration of stimuli from each task. Panel A shows a representation of stimuli in the Temporal Visual Search task. Note that participants viewed letters in a gray font on a black background. Panel B shows stimuli from the Contingent Visual Search task. Panel C shows stimuli from the Non-Contingent Visual Search task. Panel D shows an illustration of stimuli from the Involuntary Spatial Orienting task. Note that participants view gray boxes on a black background.

Study 1

The purpose of Study 1 was to explore potential predictors of attention capture in the set of capture tasks previously used in Chapter 3. Here, attention capture is examined in terms of its relationship with working memory ability as measured by the Operation Span task (Turner & Engle, 1989), self-reported attention control as measured by the Attention Control Scale (Derryberry & Reed, 2002; Douglas & Reed, 2001), and the simultaneous use of multiple forms of media as determined by the Media Multi-Tasking Index (Ophir, Nass, & Wagner, 2009).

Frequently considered a gold standard index of working memory, the Operation Span task (OSPAN; Turner & Engle, 1989) measures working memory capacity under heavy demands on executive control. The task requires participants to maintain a set of to-be-remembered words while concurrently evaluating the validity of mathematical equations that must be verbally stated aloud to prevent verbal rehearsal of the words. Thus, executive control demands are high due to the competition for attentional resources inherent in the task. Working memory (OSPAN) scores are known to be associated with other cognitive performance and fluid intelligence measures such as Raven's Progressive Matrices, memory span, reading comprehension, and the attentional blink (e.g., Arnell, Stokes, MacLean, & Gicante, 2010; Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin, & Conway, 1999; Fleischhauer et al., 2010; Salthouse & Pink, 2008; Schweizer & Moosbrugger, 2004; Unsworth & Engle, 2005). Low working memory capacity is associated with increased errors in Stroop tasks (Kane & Engle, 2003), increased capture by unexpected auditory changes (e.g., Sörqvist, 2010), and an increased likelihood of hearing one's own name in an unattended stream (e.g., Conway, Cowan, & Bunting, 2001). The intuitive hypothesis is that executive control ability as measured by the OSPAN task (higher scores indicate better control) would be negatively correlated with attention capture (greater capture costs indicate poorer attentional control) in the set of capture tasks presented here. In tasks where search sets must be maintained (e.g., contingent search tasks), working memory capacity may predict capture performance; in contrast, capture performance in non-contingent search tasks, which do not require the maintenance of search set, may not be predicted by working memory capacity as capture is defined by purely bottom-up salience irrespective of task goals.

The Attention Control Scale (Derryberry & Reed, 2002; Douglas & Reed, 2001) is a self-report questionnaire designed to estimate individual differences in voluntary attentional control during daily life. The ACS includes 20 items that produce an overall estimate of attentional control. It is frequently viewed as a single factor index of attentional control with two correlated sub-factors: Focus (e.g., “When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me.”) and Shifting (e.g., “When a distracting thought comes to mind, it is easy for me to shift my attention away from it.”). More generally, the focus component is defined as the capacity to intentionally hold attention and the intended target or modality and resisting undesired shifts to irrelevant or distracting stimuli whereas the shifting component is defined as the capacity to intentionally refocus attention to the desired stimuli. This scale is thought to best represent aspects of voluntary attentional control and so might correlate with attention capture tasks that also require such abilities. Full scale reliability is fairly high at $\alpha = .84$ (e.g., Ólafsson et al., 2011) and in our own sampling, we have also found similarly high test-retest reliability over one week ($rr = .90$).

Although the ACS has been evaluated extensively in terms of its inverse correlations with anxiety and depression such that higher levels of anxiety and/or depression are associated with a decreased ability to focus and shift attention (Ólafsson et al., 2011), relatively few studies have directly examined the ACS in terms its ability to predict objective measures of attention control.

Reinholdt-Dunne, Mogg, and Bradley (2012) did relate ACS scores to a computer-based measure of attentional control. They used the ACS to predict performance in the Attention Network Test (ANT)—which yields a behavioural measure of attentional control and the capacity to resist processing task-irrelevant flankers while identifying the orientation of a central target arrow (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Posner & Rothbart, 2007). If both the ACS and the ANT measure executive control of attention, then the ability to ignore these flankers should be positively correlated with subjective estimates of attention control as measured by the ACS. Indeed, attention control as measured by the ANT was found to be positively correlated with the Focus component of the ACS, but neither the Shifting component nor overall ACS scores.

Similarly, anti-saccade tasks, where participants must move their eyes in the direction opposite an onset target, have been used as an index of control as it requires the inhibition of reflexive eye movements toward a sudden-onset stimulus (e.g., Hallett, 1978; Schaeffer et al., 2013). Recently Judah, Grant, Mills, and Lechner (2014) related performance on an anti-saccade task to ACS scores and found that the focus component, but not the shifting component, of the ACS positively correlated with anti-saccade performance.

It is important to note that the ANT and the anti-saccade task discussed above both rely on top-down attentional control. The ANT requires participants to sort out targets (e.g., a centrally presented arrow) amongst other meaningful non-targets (e.g., peripherally presented arrows that match or do not match the direction of the target arrow). The anti-saccade task requires participants to interpret a cue (e.g., a fixation cross whose colour changes to indicate whether to look away or towards the upcoming onset target). In both cases, attentional orienting is voluntary; successful completion of the task requires efficient top-down modulation of attention settings. Given that the ACS scale is thought to underlie voluntary attentional control, one might reasonably expect that full scale ACS, and more likely the Focus subscale, would predict attention capture in the contingent capture tasks (which require specific attention search settings) but not necessarily the non-contingent capture tasks where capture is based purely on salience and not on voluntary attentional control.

The simultaneous use of multiple forms of media has increased steadily over the years and recent research has only just started to explore its cognitive and behavioural consequences. Ophir and colleagues (Ophir et al., 2009) developed a self-report questionnaire, the Media Multi-tasking Index (MMI) to assess the extent to which individuals engage in multiple media sources simultaneously (e.g., listening to music while studying). In their study, they found that individuals who engage heavily in multiple forms of media simultaneously were less able to ignore task-irrelevant distractors and showed a greater propensity for bottom-up attentional capture compared to individuals who only lightly engage multiple forms of media.

Cain and Mitroff (2011) extended this view using a colour singleton attention capture task and showed evidence that heavy media multi-taskers lacked the ability to modulate attention based on top-down control and instead their performance remained stimulus-driven regardless of task demands. Thus, heavy media multi-taskers are less efficient at filtering distractors and appropriately modulating attention to suit task demands. Heavy media multi-taskers have a comparatively liberal attentional filter which would permit more (irrelevant) information for further processing. Media Multi-tasking habits have been shown to be unrelated to self-reported attentional control as measured by the ACS (Ralph, Thomson, Cheyne, & Smilek, 2014) and so we can reasonably expect that we may find unique contributions of each measure to the prediction of individual differences in attention capture in the present set of laboratory tasks. It might be the case the ACS could tap into contingent capture measures whereas the media multi-tasking habits may be reflected in the relatively more stimulus-driven non-contingent attention capture.

Study 1 uses the five different measures of attention capture which have been previously established to be unrelated to each other in Chapter 3. By using OSPAN, ACS, and MMI, the primary goal of Study 1 is to find predictors of attention capture using measures that ostensibly characterize individual differences in executive function and attentional control. There will likely not be a single predictor for all capture tasks as each capture measure has previously been shown to be unrelated to other capture measures. However, the present set of unique predictor variables may uncover what drives the unique form of capture found in each task.

Methods

Participants

One-hundred and thirty-four undergraduate students (113 female) at Brock University participated in two, 2 hour sessions separated by one week, in exchange for research hours for a course. These were the same participants who generated capture estimates in Chapter 3. In the present study these five capture estimates will be related to the scores from the same individuals on the OSPAN, ACS and MMI measures. The study received ethics clearance from the Brock University Research Ethics Board.

Design & Procedure

All experimental stimuli were presented via a Dell desktop computer running E-Prime v1.1 (Schneider, Eschman, & Zuccolotto, 2002) and responses were made using the Dell desktop computer keyboard. The experimental session contained four computer-based attention tasks which all participants completed in the following order: 1) Temporal Visual Search 2) Non-contingent Spatial Visual Search 3) Involuntary Spatial Orienting 4) Contingent Spatial Visual Search, each described in Chapter 3. Capture cost in each task was calculated as in Chapter 3 where standardized residuals were calculated as the performance in the distractor-present condition controlling for performance in the distractor-absent condition.

After completing all four attention capture tasks, participants completed the Operation Span task on the same computer. The original procedure used by Turner and Engle (1989) was modified for use on computer. Participants viewed centrally presented mathematical operations and unrelated words on screen (e.g., (2 x 5) – 3 = 7? CHAIR). Participants were required to read the operation aloud, make a key press indicating whether the provided solution was “true” or “false” and then read the word aloud. The operation and word remained on the screen until the manual true/false response for the operation was made. After each set of operations and words, participants were prompted to serially recall all the words by writing them in the correct order on a sheet of paper. The set size varied randomly between two and six operations and words. Three sets of each size were presented, for a total of 15 sets. The span score was calculated as the total number of words that were recalled correctly in the proper order when all of the mathematical operations in a given set were correctly identified as “true” or “false”.

Following the OSPAN task, the ACS and MMI were administered via paper questionnaires. The ACS is a 20-item questionnaire with day-to-day examples of working and concentrating. Each item is rated on a four point likert scale from 1 (almost never) to 4 (always). Eleven of the 20 items are reverse-scored. Although the overall scale measures a general capacity for attentional control, it can be broadly divided into two correlated sub-components of attention: Focusing (e.g., “My concentration is good even if there is music in the room around me”), Shifting (e.g., “I can quickly switch from one task to another”). However, the scale is typically considered as a single scale containing all sub-components (Derryberry & Reed, 2002; Fajkowska & Derryberry, 2010). Scores on the ACS represent a sum of the responses and range from a minimum of 20 to a maximum of 80. A typical full scale mean score for a large sample is about 50.17 (*SD* = 7.49). Each sub-component mean is calculated separately. The focusing sub-component ranges from 9 to 36 with a mean of 23.77 (*SD* = 4.54); the shifting sub-component ranges from 11 to 44 with a mean of 26.40 (*SD* = 3.96) (Ólafsson et al., 2011).

For the MMI participants reported the number of hours per week they spend using each of a battery of 12 different forms of media (e.g., printed media such as newspapers and textbooks, television, music, video games, phone calls, text-messaging, and more). Participants then completed a media use matrix where they indicated the extent to which multiple forms of media were simultaneously used on a four point scale (0 = ‘never’ to 3 = ‘most of the time’). For example, while primarily using a given medium (e.g., printed media), participants indicated the extent to which each of the other 11 forms of media were simultaneously used. An MMI score was created in several steps as indicated by Ophir and colleagues (2009). First, for each primary medium on the matrix, the responses (e.g., 0 – 3) were summed. This produces an estimate for the mean time spent using other media while engaged in the primary medium. This number was then multiplied by the number of hours spent using each primary medium and entered as a weighted average given the overall total number of hours spent consuming all forms of media. Thus, the index score reflects the amount of multitasking that a participant engages during a typical media consumption hour.

Results and Discussion

As first described and plotted in Chapter 3, the expected pattern of capture was observed in each of the attention capture tasks. In the Temporal Visual Search task, both contingent and non-contingent capture was observed such that target identification accuracy was significantly different between all conditions. Similarly, the distractor-present condition in both the contingent and the non-contingent Spatial Visual Search tasks yield significant longer RTs than in the distractor-absent condition. The Involuntary Spatial Orienting task yield significantly longer RTs for the invalid cue condition for only the onset (contingent), and not the colour (non-contingent) cue condition. Distractor costs were calculated separately for each task and were determined using standardized residuals (see Chapter 3 for summary).

Pearson correlation coefficients between attention capture costs in each task and each of the three predictor variables (OSPAN, ACS, MMI) can be found in Table 4-1. Recall that all five capture measures showed fairly good test-retest reliability (ranging from .40 to .67). As illustrated in the table, the predictor variables showed generally high test-retest reliability. Thus, the upper limit for correlation is substantial. Additionally, relative independence of the predictor variables was observed. That is, OSPAN, ACS, and MMI scores were not significantly correlated with each other. Thus, each predictor appears to represent unique characteristics of a given participant. Although, as expected, ACS subscales correlated strongly with each other.

Importantly, none of the predictor variables was significantly related to capture in any of the computer-based attention capture tasks. Thus, attention capture, as represented by the capture tasks used here, is not related to working memory control, self-reported attentional control in day-to-day life, or by the self-reported degree of media multitasking. While attention capture remains stable over time (Chapter 3), it is not related to three likely predictors.

Table 4-1
Zero-order correlations of capture costs with predictor variables

	1	2	3	4	5
1. OSPAN	**.81****	-.01	.01	-.03	-.11
2. ACS - Full Scale		**.85****	.89**	.92**	.01
3. ACS - Shift			**.85****	.63**	-.07
4. ACS - Focus				**.71****	.04
5. MMI					--
6. Non-Contingent Temporal Search	.11	-.08	-.19	.03	-.03
7. Contingent Temporal Search	-.02	.12	.14	.07	-.06
8. Non-Contingent Spatial Search	-.17	.12	.17	.04	.19
9. Contingent Spatial Search	.01	-.16	-.21	-.08	-.06
10. Involuntary Spatial Orienting	-.13	-.01	.02	-.04	-.01

Note: Correlations based on standardized residual calculations of costs averaged across experimental sessions. The diagonal, shown in bold, in the upper section of the table represents the test-retest reliability of each measure where it could be determined. Reliability of the MMI could not be estimated because it was administered only once in session 1.
** = $p < .001$
All other *p*-values > .13

One possibility for the absence of a relationship between OSPAN and attention capture is that OSPAN may require a comparatively higher level of executive control and as such may tap into encoding and retrieval processes rather than lower-level filtering and inhibition as required in the capture tasks. Indeed, performance in the OSPAN task relies heavily upon slower, self-paced, strategic memory processes whereas the capture tasks used here rely almost exclusively on rapid filtering and inhibition trial to trial. Similarly, self-reported attentional control on the ACS may have more to do with slower voluntary processes (e.g., “When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me.”) rather than rapid filtering or vulnerability to involuntary bottom-up capture. It is possible that the top-down control characterized by the ACS is distinct from the relatively stimulus-driven capture characterized by the capture tasks here. It is unclear why media-multitasking would be unrelated to capture in any of the tasks as it is known to be related to failures of cognitive control (Ophir et al., 2009), reduced attentional filtering (Cain & Mitroff, 2011), higher impulsivity and lower working memory (Minear, Brasher, McCurdy, Lewis, & Younggren, 2013). In line with the results of Study 1, and in contrast with the results of Cain and Mitroff (2011), Minear and colleagues (2013) found no association between MMI and performance in the ANT task in terms of distractor interference or task switching. As suggested by Minear and colleagues, the difference may lie in the way the task is structured. Specifically, Cain and Mitroff structured the task such that conditions were blocked (e.g., one block of sometimes valid followed by one block of never valid distractor cues) which may encourage the adoption of a condition-specific attentional strategy. Indeed, Cain and Mitroff suggest that the effective use of attentional strategies may underlie the difference between High and Low media-multitaskers. In Study 1, and Minear and colleagues, conditions were always mixed (e.g. valid and invalid) such that an attentional strategy centred on cue validity could not be formed. What may be needed is a set of self-report measures that more directly reflects failures of attention or the failure to appropriately allocate resources to targets while simultaneously filtering non-target stimuli without specific regard for block-level attention strategies.

Study 2

The purpose of Study 2 was to extend the scope covered by the self-report measures in Study 1. To this end, a total of eleven questionnaires were included, including the ACS, each of which was designed to evaluate different aspects of day-to-day attentional functioning. These questionnaires were selected based on their breadth of domain and function. In study 1, predictor variables were limited to those that were known to relate to performance in tasks that require attentional control (e.g., Arnell, Stokes, MacLean, & Gicante, 2010; Baddeley, Chincotta, &

Adlam, 2001; Judah et al., 2014; Miyake et al., 2000). In Study 2, a more liberal selection criterion was employed and measures were selected if they were broadly associated with attentional control ability, cognitive failures, lapses of attention, impulsivity, boredom proneness, and propensity to mind-wander. Each of the measures used is introduced separately below in the order in which they were administered.

Methods

Participants

A total of 129 undergraduate students (114 female) at Brock University participated in a single 3–hour testing session exchange for research hours for a course. Mean age was 20.15 years with a range of 18 to 41 years of age. All participants reported normal or corrected-to-normal visual acuity and no colour blindness. None had participated in Study 1. A total of four participants were eliminated from the analysis: 2 did not complete all the tasks, and 2 showed capture costs that fell beyond +/- 3 standard deviations from the group mean. The final sample size for the present analysis was 125 (110 female) with a mean age of 20.04 years. The study received ethics clearance from the Brock University Research Ethics Board.

Design & Procedure

All stimuli were presented via a Dell desktop computer running E-Prime v1.1 (Schneider et al., 2002) and responses were made using the Dell desktop computer keyboard. The experimental session contained the same four computer-based attention tasks described in Study 1. After completing all four attention capture tasks, participants completed self-report questionnaires in the order in which they are presented below.

The Mind Wandering Spontaneous and Deliberate Scale (Carriere, Seli, & Smilek, 2013) is a short 8-item self-report scale that measures an individual’s tendency to mentally drift away from the primary task. There are two 4-item subscales: Spontaneous, the degree to which an individual's thoughts unintentionally drift away from the task (e.g., "I find my thoughts wandering spontaneously.") and Deliberate, the degree to which an individual's thoughts are intentionally refocused away from the task (e.g., "I allow my thoughts to wander on purpose."). Each question is answered on a scale of 1 (rarely or not at all true) to 7 (always of very true). Each subscale typically shows a mean score of approximately 4.0 to 4.5, is moderately correlated with the other subscale (r = .50), and weakly but significantly positively correlated with the ACS subscales. Mind wandering is thought to reflect one's ability to sustain attention over extended periods of time and is known to impair performance on working memory tests. It is generally thought to represent failures of control in contexts such as a laboratory experiment (for a review, see Mooneyham & Schooler, 2013).

The Mindful Attention Awareness Scale Lapses-Only (Brown & Ryan, 2003; Carriere, Cheyne, & Smilek, 2008) is a modified version of MAAS (Brown & Ryan, 2003) self-report measure of everyday mindlessness. High scores on the scale represent a greater proneness to attentional lapses (e.g., the loss of attention to present events and experiences). Statements such as "I break or spill things because of carelessness, not paying attention, or thinking of something else" are rated on a scale of 1 (almost never) to 6 (almost always). Scores on this questionnaire are summed, and they range from 7 to 72. Scores tend to be positively related to failures in sustained attention, cognitive failures, and proneness to boredom as well as neuroticism, depression, and physical health problems (Brown & Ryan, 2003).

The Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, FitzGerald, & Parkes, 1982) is a 25 item self-report measure of everyday failures in perception, memory, and motor function. It includes day-to-day failures that many individuals can identify with such as forgetting appointments, failing to notice street signs, or misplacing items such as a newspaper or keys. Participants estimate the extent to which they experience statements such as “Do you find you forget whether you’ve turned off a light or a fire or locked the door?” and “Do you read something and find you haven’t been thinking about it and must read it again?” on a scale of 0 (never) to 4 (very often). Scores range from 0 to 100 and higher scores indicate higher levels of cognitive failures. CFQ scores are negatively associated with measures such as the attention-control scale but positively associated with trait and state levels of anxiety and depression. The CFQ is thought to underlie deficits is attentional focus (Judah et al., 2014) and efficient inhibition (Berggren, Hutton, & Derakshan, 2011).

The Attention-Related Cognitive Errors scale (ARCES; (Cheyne, Carriere, & Smilek, 2006) was developed using some items from the CFQ (along with new items created specifically for this scale) that more specifically are associated with attention-related rather than cognition-based errors. It is considered a more clearly specified measure of attention-related cognitive failures than the CFQ and is associated with a direct measure of the ability to sustain attention (or the mindlessness therein) reported by the MAAS scale and only weakly associated with boredom proneness—particularly after accounting for the relationship between MAAS and boredom proneness (Cheyne et al., 2006; Smilek, Carriere, & Cheyne, 2010). The ARCES scale contains statements related to attentional errors in day-to-day life such as “I have gone into a room to get something, got distracted, and wondered what I went there for.” and “I make mistakes because I am doing one thing and thinking about another.” Each of these statements is rated on a scale from 1 (never) to 5 (very often). Overall, this scale will be used as a measure of daily errors in attention to contrast with the cognitive-based errors measured by the CFQ.

The Cognitive and Affective Mindfulness Scale (CAMS; (Feldman, Hayes, Kumar, Greeson, & Laurenceau, 2006) is an 12-item self-report measure designed to capture mindfulness in broad terms. Historically used to gauge the efficacy of mindfulness training in depressed individuals, it contains components of attention, focus on the present moment, self-awareness and acceptance. In comparison to the MAAS scale, the CAMS contains similar elements of attention awareness but also includes attitudinal components of acceptance and non-judgment. For example, the scale contains items such as, “I am able to accept the thoughts and feelings I have.” and “I am able to focus on the present moment.” Thus, it characterizes attentional focus with an emotional element to it. These statements are self-rated in terms of the degree to which they apply on a scale of 1 (rarely) to 5 (always). The scale is positively related to mindfulness as measured by the MAAS and negatively associated with trait depression and anxiety (Feldman, et al, 2006).

The Need for Cognition Scale (Cacioppo & Petty, 1982) is an 18-item self-report questionnaire that measures the tendency for an individual to engage in and enjoy complex thought. It’s a highly reliable scale producing a Cronbach’s alpha of .92 and a test-retest reliability of .88 (Sadowski & Gulgoz, 1992). Items such as, “I would prefer complex to simple problems.” and “I only think as hard as I have to” are rated on a scale from 1 (completely false) to 4 (completely true). Those with a higher need for cognition tend to elaborate more on thought, and tend have higher fluid intelligence than low NFC individuals (Fleischhauer et al., 2010) and thus they may be expected to perform better on attention tasks (Arnell et al., 2010; Kane & Engle, 2002). Conversely, high NFC individuals have also been shown to be more susceptible to the creation of false memories as a result of unnecessary elaboration to non-studied (or non-target) items (Petty, Brinol, Loersch, & McCaslin, 2009). Thus, to the extent that they would needlessly process and elaborate task-irrelevant stimuli in a capture task, high NFC individuals could also be expected to perform worse.

The cognitive reflection test (CRT; Frederick, 2005) is a short 3-item test that measures the tendency to inhibit or override an incorrect intuitive or prepotent response and engage in further reflection that eventually leads to the correct answer. Take, for example, the question, “A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?” The intuitive answer is that the ball costs 10 cents because $1.10 - $1.00 is 10 cents. However, the correct answer is that the ball costs 5 cents. This test is highly correlated with measures of intelligence and executive control but it also predicts heuristic and biased processing (e.g., gambler’s fallacy, base-rate problem, or sunken cost problem) even after controlling for intelligence and executive control which suggests that the CRT uniquely measures the tendency to superficially process information (Toplak, West, & Stanovich, 2011). Thus, it may be associated with increased errors in vigilance or rapid information processing in capture tasks.

The Barratt Impulsiveness Scale (BIS; Barratt, 1959) is a 30-item self-report questionnaire that measures an individual’s personal impulsiveness. Items such as, “I do things without thinking.” and “I don’t pay attention” are rated on a scale from 1 (rarely/never) to 4 (almost always or always). The scale produces a six factor solution with the following subscales of impulsivity: Attention (“focusing on the task at hand”), Motor Impulsiveness (“acting on the spur of the moment”), Self-control (“planning and thinking carefully”), Cognitive Complexity (“enjoy challenging mental task”), Perseverance (“a consistent life style”), and Cognitive Instability (“thought insertions and racing thoughts”). Its utility is well-documented and it is a widely adopted measure in both research and clinical settings. The scale and its sub-factors are known to be associated with personality facets, psychological disorders, and with a wide range of individual differences such as inhibition, boredom susceptibility, and other attention-related phenomena (for a review see Stanford et al., 2009). For the purposes of the present study, it is used as an estimate of the capability of an individual to modulate cognition and behaviour based on the demands of the task or environment. Individuals who self-report as more impulsive in day-to-day functioning may reflect a more impulsive attentional profile where ineffective filtering or inhibition strategies may prevail—leading to a greater degree of capture.

The Boredom Proneness Scale (BPS; Farmer & Sundberg, 1986) is a 28-item self-report questionnaire that measures an individual's susceptibility to boredom in day-to-day life. Statements such as, "It would be very hard for me to find a job that is exciting enough" and "time always seems to be passing slowly" are rated on a scale from 1 (strongly disagree) to 7 (strongly agree) where higher scores on the scale represent a greater degree of boredom. The scale has found to be a reliable and valid measure of boredom proneness across a number of studies (e.g., Malkovsky, Merrifield, Goldberg, & Danckert, 2012; Vodanovich & Kass, 1990; Vodanovich, Wallace, & Kass, 2005; Wallace, Vodanovich, & Restino, 2002). The BPS scale is known to relate positively to the CFQ such that individuals who are more susceptible to boredom are also more likely to exhibit cognitive failures in day-to-day life (Wallace, Vodanovich, & Restino, 2003).

Results and Discussion

Response times (RTs) were included in analyses only for correct target identifications. Individual participant RTs were also subjected to an outlier removal procedure that removed RTs that fell beyond +/- 3 Standard Deviations from each individual's mean RT in each condition. For all capture measures, the expected pattern of means was found.

Mean target accuracy scores for the Temporal Visual Search task were submitted to an ANOVA in which distractor condition (none, gray, different colour, same colour) was entered as a within-subjects factor. See Figure 4-2A for means. Results indicated a significant main effect of distractor condition, $F(3, 369) = 197.60$, $p < .001$, $\eta^2 = .616$. Follow-up paired-samples t-tests indicated that all pairs of means were significantly different, all *p*s < .001. These results indicate that both contingent and non-contingent attention capture occurred in this task as expected.

Response times in the Non-Contingent Spatial Visual Search task were submitted to a paired-samples t-test where distractor condition was a within-subjects factor. See Figure 4-2B for means. Results indicated a significant effect of distractor condition, $t(124) = 13.03$, $p < .001$, $d = .46$, where RTs were longer for the distractor condition compared to the no distractor condition, indicating the presence of attention capture in this task. A similar pattern was observed for the Contingent Spatial Search task. A paired-samples t-test indicated a significant effect of distractor condition where RTs were significantly longer when the distractor was present versus absent, $t(124) = 14.09$, $p < .001$, $d = .45$, demonstrating that the expected attention capture occurred in this task. See Figure 4-2C for means.

Response times in the Involuntary Spatial Orienting task were submitted to an ANOVA in which cue type (onset vs colour) and cue validity (valid vs invalid) were entered as within-subjects factors. See Figure 4-2D for means. Overall, results indicated a significant main effect of cue validity, $F(1, 124) = 116.88$, $p < .001$, $\eta^2 = .487$ but no main effect of cue type, $F(1, 124) = .019$, $p = .889$, $\eta^2 = .00$. Importantly, a significant interaction between cue validity and cue type was observed, $F(1, 124) = 85.56$, $p < .001$, $\eta^2 = .410$. Follow-up t-tests performed separately for each cue type indicated that capture occurred for both onset cues (valid vs invalid), $t(124) = 12.75$, $p < .001$, $d = .80$, and for colour cues (valid vs invalid): $t(124) = 2.38$, $p = .019$, $d = .12$, but, as indicated by the significant interaction, cost was significantly larger for onset cues (Mean cost = 50ms, SD = 43) than for colour cues (Mean cost = 7ms, SD = 34), replicating the pattern of results observed by Folk et al. (1992) where capture in this task is larger when distractors share at least one feature with the target.

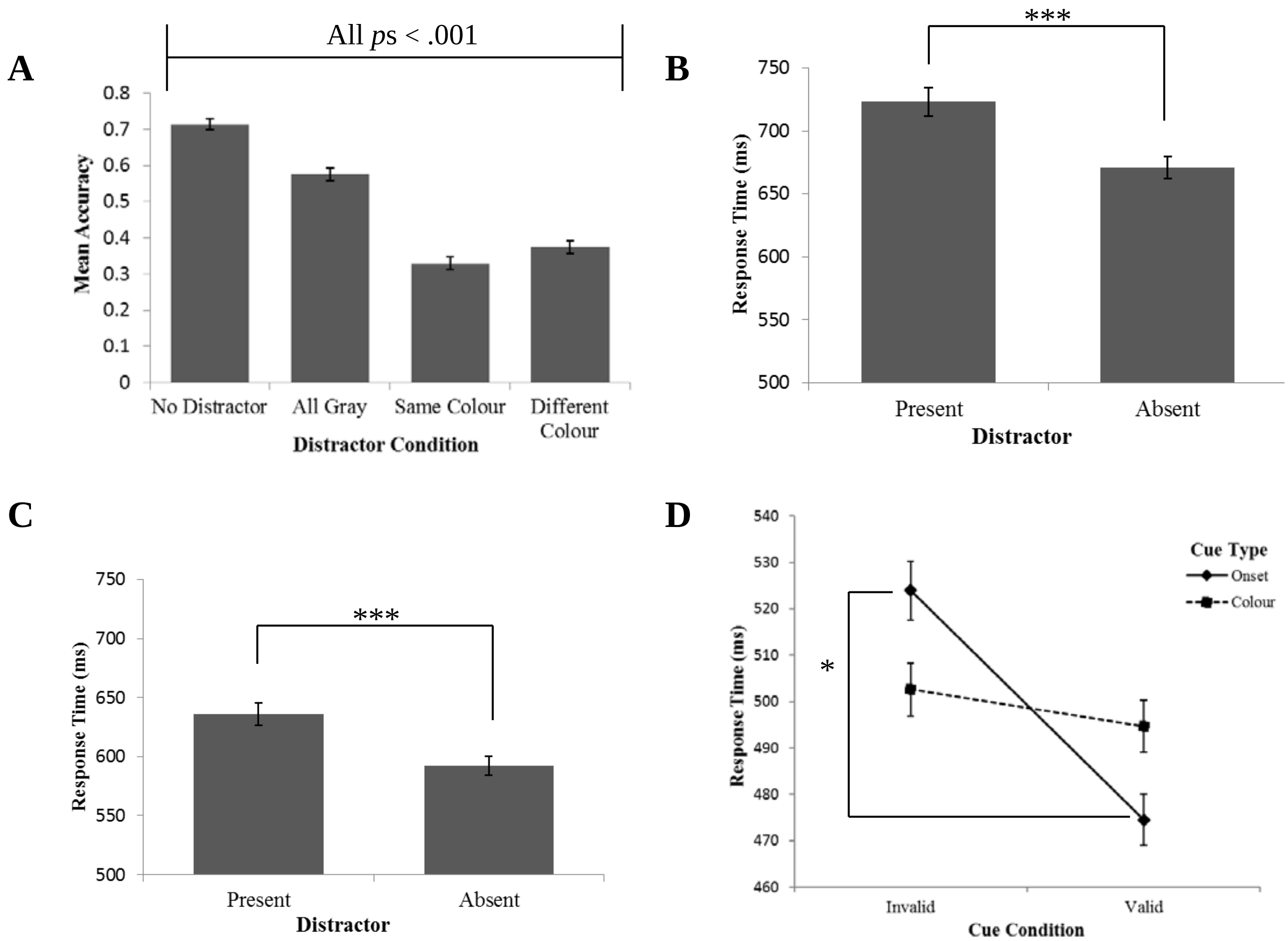

Figure 4-2. Dependent variable means from each of the capture tasks. In all cases error bars represent +/- 1 standard error of the mean. Panel A shows mean target identification accuracy as a function of distractor condition in the temporal visual search task. Non-contingent cost is the difference between the No Distractor and the All Gray conditions; Contingent cost is the difference between the All Gray condition and the mean of the two colour conditions. Panel B shows mean correct-identification response times as a function of the distractor presence in the Non-Contingent Visual Search task. Panel C shows mean correct-identification response times as a function of the distractor presence in the Contingent Visual Search task. Panel D shows the results from the Involuntary Spatial Orienting task: Mean correct-identification response times as a function of the cue validity (horizontal axis) and cue type (separate lines).

Attention capture costs in each task were calculated as in Study 1. Standardized residuals (i.e., the variability in the distractor condition after controlling for the variability in the non-distractor condition) were used in all cases[7]. As in Chapter 3, capture was found to be reliable and stable within individuals within session. When internal-consistency reliability of the 5

[7] The same pattern was observed when using difference scores.

capture measures was estimated within session with a split-half (odd/even trials), and a Spearman–Brown correction was applied, reliability here approximated the reliability estimates of the sample in Chapter 3. Reliability estimates were .45, .62, .65, .33, and .60 for non-contingent temporal search, contingent temporal search, non-contingent visual search, contingent visual search and involuntary spatial orienting respectively. As first observed in Chapter 3 where capture did not generalize between tasks, zero-order Pearson correlations coefficients showed a similar range from -.05 to .14 (all non-significant).

Zero-order Pearson correlation coefficients between attention capture measures and each of the self-report questionnaires can be found in Table 4-2. Each measure is known to be reliable and have good internal consistency. However, no self-report measure convincingly predicted attention capture in any of the capture tasks in the present study. Given that the attention capture tasks themselves are un-related to each other (Chapter 3), one might have expected that attention capture a given task could be independently predicted by unique self-report measures that do not predict performance in other capture tasks. In this manner, there are several correlations that showed promise under the Contingent Temporal Search task, but their magnitude was modest and after applying a Bonferroni correction for 21 comparisons, these were no longer significant. These correlations were most likely the result of a Type I error, but it is worth considering that each of these 4 relationships was in the predicted direction where reduced self-reported attentional control predicted greater capture. However, there is no a-priori hypothesis for why only the Contingent Temporal Search task would show relationships with these specific measures.

Most of the self-report measures were highly correlated with each other. Table 4-3 displays the zero-order Pearson correlations between each of the self-report measures. This set of correlations stands in stark contrast to the set observed in Table 4-1. Many of the significant correlations were robust to the Bonferroni correction as they were larger in magnitude and significant at the $p < .001$ level. What this overall pattern suggests it that, with the possible exception of the Mind-Wandering Deliberate scale, the Cognitive Reflection Test, and the Barratt Impulsiveness Full Scale score, all the self-report measures tended to reflect the same set of executive functions, which in turn, were unrelated to capture in the set of tasks used here.

Table 4-2
Zero-order correlations of self-report measures with standardized computer-based capture costs.

	Non-Contingent Temporal Search	Contingent Temporal Search	Non-Contingent Spatial Search	Contingent Spatial Search	Involuntary Spatial Orienting
1. MW-D	.06	.08	.11	.05	-.01
2. MW-S	.02	.07	.08	.00	-.08
3. MW-T	.05	.09	.12	.03	-.06
4. ACS-Focus	.00	-.20*	-.05	.07	-.02
5. ACS-Shift	.09	-.07	-.04	.11	.02
6. ACS-Total	.06	-.15	-.05	.11	.00
7. MAAS-LO	.06	.15	.00	.13	.01
8. CFQ	-.04	.27*	-.08	.03	-.03
9. ARCES	-.02	.18*	.05	-.02	.09
10. CAMS	.06	-.11	.03	-.07	.04
11. NFC	-.14	.10	-.11	.16	-.03
12. CRT	.03	.07	-.12	.00	-.10
13. BIS-Att	.03	.09	.07	-.05	.05
14. BIS-CI	-.06	.23*	.15	-.04	-.02
15. BIS-Motor	-.07	-.06	.03	-.09	.20*
16. BIS-Pers	.03	.12	.09	-.03	.04
17. BIS-Cont	-.03	.01	-.01	.03	-.14
18. BIS-CC	-.01	-.06	.04	-.07	.07
19. BPS	.00	.07	.06	.01	.03
20. MMI	-.10	.02	-.05	.12	-.01
21. MMI-ContTx	-.13	.03	-.04	.10	-.04

Note: Self-report paper measures are listed in the first column. Cost measure for each task is based on standardized residual calculation. MW-D (Mind-wandering Deliberate subscale), MW-S (mind-wandering Spontaneous subscale), MW-T (mind-wandering total score), ACS-Focus (Attentional Control Scale Focus subscale), ACS-Shift (ACS shift subscale), MAAS-LO (Mindful Attention Awareness Scale – Lapses Only), CFQ (Cognitive Failures Questionnaire), ARCES (Attention-related Cognitive Errors Scale), CAMS (Cognitive and Affective Mindfulness Scale), NFC (Need for Cognition), CRT (Cognitive Reflection Test), BIS-Att (Barratt Impulsiveness Scale – Attention subscale), BIS-CI (BIS-Cognitive Instability subscale), BIS-Motor (BIS-Motor Impulsivity subscale), BIS-Pers (BIS-Perseverance subscale), BIS-Cont (BIS-Self-Control subscale), BIS-CC (BIS-Cognitive Complexity subscale), BPS (Boredom Proneness Scale), MMI (Media-multi-tasking Index), MMI-ContrText (MMI score after controlling for amount of daily texts sent and received).

* = $p < .05$ (note that after applying a Bonferroni correction for 21 comparisons, none of these values is significant)
All other p-values > .13

Table 4-3
Zero-order correlations between self-report measures.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1. MW-D	.24*	.76**	-.02	-.08	-.06	.19*	.18-	.14	-.11	.11	.08	-.07	.15	.22**	.08	-.03	.11	-.14	.13	.00	-.03
2. MW-S	--	.80**	-.41**	-.32**	-.42**	.44**	.43**	.41**	-.36**	-.09	.10	-.05	.51**	.53**	.19*	.18**	.30**	.11	.41**	.28**	.27**
3. MW-T		--	-.29**	-.27**	-.32**	.40**	.39**	.35**	-.30**	.00	.11	-.08	.44**	.49**	.18*	.09	.27**	-.01	.35**	.19*	.15
4. ACS-F			--	.48**	.84**	-.36**	-.46**	-.41**	.46**	.31**	.02	.06	-.47**	-.27**	-.10	-.11	-.20*	-.26**	-.38**	-.19*	-.16
5. ACS-S				--	.88**	-.38**	-.57**	-.49**	.50**	.39**	-.07	.03	-.46**	-.22*	.06	-.24**	-.33**	-.22*	-.44**	-.22*	-.20*
6. ACS-T					--	-.43**	-.61**	-.52**	.56**	.41**	-.04	.06	-.54**	-.29**	-.02	-.21*	-.32**	-.28**	-.48**	-.24**	-.21*
7. MAAS						--	.57**	.53**	-.48**	-.26**	-.04	-.12	.41**	.45**	.13	.16	.40**	.10	.60**	.33**	.28**
8. CFQ							--	.72**	-.47**	-.30**	.04	-.09	.53**	.46**	.13	.20**	.44**	.15	.53**	.38**	.32**
9. ARCES								--	-.41**	-.32**	-.08	.02	.50**	.47**	.23*	.10	.31**	.29**	.50**	.47**	.44**
10. CAMS									--	.28**	.10	.14	-.55**	-.30**	.03**	-.07	-.43**	-.22**	-.58**	-.36**	-.32**
11. NFC										--	.21*	.22*	-.32**	-.07	-.08	-.09	-.29**	-.65**	-.37**	-.27**	-.18*
12. CRT											--	.11	.06	.02	.02	.06	-.02	-.32**	-.07	-.24**	-.17
13. BIS-Full												--	-.02	-.13	-.23**	-.18*	-.52**	-.36**	-.17	-.14	-.10
14. BIS-Att													--	.47**	.28**	.30**	.48**	.32**	.58**	.33**	.30**
15. BIS-CI														--	.35**	.23**	.27**	.06	.50**	.16	.15
16. BIS-M															--	.17	.34**	.31**	.21*	.18*	.17
17. BIS-P																--	.33**	.15	.26**	.13	.10
18. BIS-CT																	--	.31**	.53**	.40**	.36**
19. BIS-CC																		--	.27**	.27**	.24**
20. BPS																			--	.27**	.23**
21. MMI																				--	.94**
22. MMI-Cn																					--

Note: Self-report paper measures are listed in the first column. Cost measure for each task based on standardized residual calculations of costs. MW-D (Mind-wandering Deliberate subscale), MW-S (mind-wandering Spontaneous subscale), MW-T (mind-wandering total score), ACS-Focus (Attentional Control Scale Focus subscale), ACS-Shift (ACS shift subscale), MAAS (Mindful Attention Awareness Scale), CFQ (Cognitive Failures Questionnaire), ARCES (Attention-related Cognitive Errors Scale), CAMS (Cognitive and Affective Mindfulness Scale), NFC (Need for Cognition), CRT (Cognitive Reflection Test), BIS-Full (Barratt Impulsiveness Full Scale score, BIS-Att (BIS-Attention subscale), BIS-CI (BIS-Cognitive Instability subscale), BIS-M (BIS-Motor Impulsivity subscale), BIS-P (BIS-Perseverance subscale), BIS-CT (BIS-Self-Control subscale), BIS-CC (BIS-Cognitive Complexity subscale)), BPS (Boredom Proneness Scale), MMI (Media-multi-tasking Index), MMI-Cnt (MMI score after controlling for amount of daily texts sent and received).
** = $p < .001$
* = $p < .05$
All other *p*-values > .13

The correlations in Table 4-3 are not universally high suggesting that there may be unique overlap between some measures as well as discriminant non-relationships between others. To explore this possibility, a principal components factor analysis was conducted on the set of 21 self-report (sub-) scales. The communalities of the variables included were generally high overall with the exception of the mind-wandering-deliberate measure which loaded onto Factor 2. The KMO (.842) and Bartlett's test of sphericity (931.96, $p < .001$) were both high, indicating that the set of variables are sufficiently related for factor analysis.

The analysis yielded an un-rotated four-factor solution explaining a total of 59.83% of the variance in the entire set of measures[8]. See Table 4-4. Factor 1 was labeled "Spontaneous Errors" due to the relatively high loadings of measures characterized by attentional failures, momentary cognitive failures, and switching-related sources of executive failures. This factor encompassed 12 of the 18 components entered in the factor analysis and it shows the highest Eigenvalue by a wide margin, which makes it tempting to declare the analysis a single-factor solution. However, three additional factors emerged. Factor 2, was labelled "Effortful Persistence" given the high loadings from measures characterized by deliberate or effortful cognitive control. This factor comprised four measures such as the Need for Cognition or the Cognitive Complexity component of the Impulsivity scale and explained 10.54% of the variance. Factor 3 included only the Motor component of the impulsivity scale (7.98% of the variance) and Factor 4 included only the Perseverance component of the impulsivity scale (6.48% of the variance). Given that these two subcomponents did not predict capture in any of the tasks (as seen in Table 4-2), Factor 3 and Factor 4 were not expected to additionally account for variance in the capture tasks. Overall, the factor analysis suggested that there were primarily two factors

[8] A Varimax rotated solution was also explored, but produced a less logical arrangement of variables into a four-factor solution. The rotated solution accounted for less variance than the un-rotated solution and did not predict capture in any of the tasks.

represented by the set of self-report measures used here: one that was characterized by spontaneous errors and one that was characterized by relatively slower effortful persistence.

Table 4-4
Factor analysis of self-report measures.

		Loadings				
		Factor 1 (Spontaneous Errors)	Factor 2 (Effortful Persistence)	Factor 3 (BIS-Motor Impulsivity)	Factor 4 (BIS-Motor Perseverance)	Communalities
1.	MW-D		**.502**		.346	.410
2.	MW-S	**.626**	.351			.524
3.	ACS-Focus	**-.607**				.477
4.	ACS-Shift	**-.655**		.411	.328	.705
5.	MAAS-LO	**.706**				.573
6.	CFQ	**.783**				.672
7.	ARCES	**.751**				.631
8.	CAMS	**-.692**		.340		.597
9.	NFC	-.492	**.630**			.667
10.	CRT		**.574**		-.558	.645
11.	BIS-Att	**.776**				.641
12.	BIS-CI	**.605**	.383			.617
13.	BIS-Motor	**.310**		**.780**		.710
14.	BIS-Pers	**.333**		.382	**-.543**	.551
15.	BIS-Cont	**.637**		.312		.525
16.	BIS-CC	.425	**-.714**			.744
17.	BPS	**.780**				.610
18.	MMI	**.523**			.352	.471
	Eigenvalue	6.27	1.90	1.44	1.17	
	% of Total Variance	34.83	10.54	7.98	6.48	
	Total Variance		45.37	53.35	59.83	

Note: Coefficients less than .30 have been excluded from the table. Variables entered into composites for later analysis are presented in bold.

The four factors were then correlated with each capture measure. The zero-order Pearson correlations are presented in Table 4-5. With the exception that the Contingent Temporal Search cost measure was significantly related to Factor 2 (Effortful Persistence), none of the factors significantly predicted any cost measure in any of the capture tasks. As in the zero-order correlations presented in Table 4-2, the Contingent Temporal Search cost was also the odd capture task that showed some small correlations with Factor 2. However, the individual self-report measures that were significantly related to contingent temporal search capture in the zero-order correlations are not primarily contained in Factor 2. In the zero-order correlations, the ACS-Focus, CFQ, ARCES, and BIS-CI, were each related to Contingent Temporal Search cost. However, these four measures are only weakly, if at all, included in Factor 2.

Table 4-5.
Zero-order Pearson correlations between the four factors and standardized capture in each task.

	Non-Contingent Temporal Search	Contingent Temporal Search	Non-Contingent Spatial Search	Contingent Spatial Search	Involuntary Spatial Orienting
F1. Spontaneous Errors	-.02	.16	.06	-.01	.004
F2. Effortful Persistence	.00	.20*	.00	.08	-.09
F3. Motor Impulsivity	-.02	-.08	.07	-.04	.10
F4. Motor Perseverance	-.04	.00	.02	.14	.05

Note:
**p* = .022. The Bonferroni correction for 20 comparisons would require a p-value less than .0025.

The two factors identified in the factor analysis were then re-created as composite variables from their constituent measures. The measures presented in bold in Table 4-4 were entered, equally weighted, into a new variable representing that factor. Factor 3 and Factor 4 were not included as they were comprised primarily of a single measure and so would not provide additional predictive utility over and above that single measure. Table 4-6 shows these correlations. None of the correlations reached statistical significance, consistent with the previous analyses showing that attention capture is not predicted by these self-report measures even when computed as factors.

In addition to the self-report measures, participants also answered a set of demographic questions (see Appendix) containing items that could conceivably relate to attention capture (e.g., Age, Sex, GPA). However, none of these demographic dimensions related to attention capture in any of the tasks presented here.

Table 4-6.
Zero-order Pearson correlations between the two composite variables based on factor analysis and cost in each task.

	Non-Contingent Temporal Search	Contingent Temporal Search	Non-Contingent Spatial Search	Contingent Spatial Search	Involuntary Spatial Orienting
F1. Spontaneous Errors	.00	.07	.09	.00	.04
F2. Effortful Persistence	-.15	.11	-.09	.17	-.02

Note: None of the coefficients reached statistical significance.

Conclusions

Attention capture has proven difficult to predict. Across two studies, attention capture costs were determined using a set of well-known and reliable attention capture tasks. Previous work has found that capture does not generalize between tasks despite good test-retest reliability (see Chapter 3). The primary goal of the present set of studies was to predict individual differences in attention capture using established self-report measures of general cognitive and attentional ability. Across two studies, using large samples, no evidence was found for the prediction of attention capture by self-report measures of attentional control, executive control of working memory scores, or media multitasking use. Study 1 examined the ability of the Attention Control Scale (Derryberry & Reed, 2002), the Operation-Span task (Turner & Engle, 1989), and the media-multitasking index (Ophir et al., 2009), to predict individual differences in five different attention capture measures. However, none of these measures was able to predict capture in any of the tasks used here. Study 2 expanded the list of potential predictors of capture to include a much broader range of self-report measures but also found little evidence that such measures could predict individual differences in attention capture.

Taken together, the results suggest that rapid online attention capture is not related to offline self-report measures of attentional ability. This could stem from one of two possibilities. First, it is possible that individuals are simply poor judges of their own attentional ability. It is a well-established observation that individuals are inaccurate self-assessors across a wide range of tasks (e.g., Dunning, Johnson, Ehrlinger, & Kruger, 2003; Falchikov & Boud, 1989). However, scores on the self-reported attentional measures correlated quite highly with each other, suggesting the presence of consistent, although possibly still inaccurate, self-assessments. Furthermore, inaccurate self-assessment would not explain why tasks such as the OSPAN, which do not rely on self-report, failed to account for variance in capture scores. Another possibility is that, unlike day-to-day patterns of attentional failures and successes, attention capture is not a trait-like characteristic of individuals. Capture may only be reliable over time for an individual due to specific conditions that exist within a specific capture task, but not more broadly in various real-world situations. That is, it is possible that capture is determined moment-to-moment by state and stimulus factors unique to each combination of task and individual rather than by trait properties of individuals. For example, reliable within-task attention capture for an individual may be the result of their individual inhibitory and excitatory weightings for various target and distractor features for that task—conditions that would not generalize outside of that specific task. Furthermore, such weightings may change trial-to-trial as weightings are adjusted and attentional control waxes and wanes over trials. This possibility will be examined further in Chapter 5 and this idea will be expanded-upon in the General Discussion.

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Appendix of Self-Report Measures

Mind-wandering Deliberate/Spontaneous

For the following statements please enter the answer that most accurately reflects your everyday mind wandering. Choose your number based on the scale below.

1	**2**	**3**	**4**	**5**	**6**	**7**
Rarely						Always
Not at all true						Very true

I allow my thoughts to wander on purpose	
I enjoy mind-wandering	
I find mind-wandering is a good way to cope with boredom	
I allow myself to get absorbed in pleasant fantasy	
I find my thoughts wandering spontaneously	
When I mind-wander my thoughts tend to be pulled from topic to topic	
It feels like I don’t have control over when my mind wanders	
I mind-wander even when I’m supposed to be doing something else.	

Attention Control Scale

Please answer each of the questions below by circling the number that best represents your response.

1. It's very hard for me to concentrate on a difficult task when there are noises around.

1	2	3	4
Almost Never	Sometimes	Often	Always

2. When I need to concentrate and solve a problem, I have trouble focusing my attention.

1	2	3	4
Almost Never	Sometimes	Often	Always

3. When I am working hard on something, I still get distracted by events around me.

1	2	3	4
Almost Never	Sometimes	Often	Always

4. My concentration is good even if there is music in the room around me.

1	2	3	4
Almost Never	Sometimes	Often	Always

5. When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me.

1	2	3	4
Almost Never	Sometimes	Often	Always

6. When I am reading or studying, I am easily distracted if there are people talking in the same room.

1	2	3	4
Almost Never	Sometimes	Often	Always

7. When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.

1	2	3	4
Almost Never	Sometimes	Often	Always

8. I have a hard time concentrating when I'm excited about something.

1	2	3	4
Almost Never	Sometimes	Often	Always

9. When concentrating I ignore feelings of hunger or thirst.

1	2	3	4
Almost Never	Sometimes	Often	Always

10. I can quickly switch from one task to another.

1	2	3	4
Almost Never	Sometimes	Often	Always

11. It takes me a while to get really involved in a new task.

1	2	3	4
Almost Never	Sometimes	Often	Always

12. It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures.

1	2	3	4
Almost Never	Sometimes	Often	Always

13. I can become interested in a new topic very quickly when I need to.

1	2	3	4
Almost Never	Sometimes	Often	Always

14. It is easy for me to read or write while I'm also talking on the phone.

1	2	3	4
Almost Never	Sometimes	Often	Always

15. I have trouble carrying on two conversations at once.

1	2	3	4
Almost Never	Sometimes	Often	Always

16. I have a hard time coming up with new ideas quickly.

1	2	3	4
Almost Never	Sometimes	Often	Always

17. After being interrupted or distracted, I can easily shift my attention back to what I was doing before.

1	2	3	4
Almost Never	Sometimes	Often	Always

18. When a distracting thought comes to mind, it is easy for me to shift my attention away from it.

1	2	3	4
Almost Never	Sometimes	Often	Always

19. It is easy for me to alternate between two different tasks.

1	2	3	4
Almost Never	Sometimes	Often	Always

20. It is hard for me to break from one way of thinking about something and look at it from another point of view.

1	2	3	4
Almost Never	Sometimes	Often	Always

Mindful Attention Awareness Scale

Below is a collection of statements about your everyday experience. Using the 1–6 scale below, please indicate how frequently or infrequently you currently have each experience. Please answer according to what really reflects your experience rather than what you think your experience should be.

1	2	3	4	5	6
Almost always	Very frequently	Somewhat frequently	Somewhat infrequently	Very infrequently	Almost never

I could be experiencing some emotion and not be conscious of it until some time later.	
I break or spill things because of carelessness, not paying attention, or thinking of something else.	
I find it difficult to stay focused on what's happening in the present.	
I tend to walk quickly to get where I'm going without paying attention to what I experience along the way.	
I tend not to notice feelings of physical tension or discomfort until they really grab my attention.	
I forget a person's name almost as soon as I've been told it for the first time.	
It seems I am "running on automatic" without much awareness of what I'm doing.	
I rush through activities without being really attentive to them.	
I get so focused on the goal I want to achieve that I lose touch with what I am doing right now to get there.	
I do jobs or tasks automatically, without being aware of what I'm doing.	
I find myself listening to someone with one ear, doing something else at the same time.	
I drive places on "automatic pilot" and then wonder why I went there.	
I find myself preoccupied with the future or the past.	
I find myself doing things without paying attention.	
I snack without being aware that I'm eating.	

The Cognitive Failures Questionnaire

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to your in the past 6 months. Please circle the appropriate number.

		Very often	Quite often	Occasionally	Very rarely	Never
1.	Do you read something and find you haven't been thinking about it and must read it again?	4	3	2	1	0
2.	Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
3.	Do you fail to notice signposts on the road?	4	3	2	1	0
4.	Do you find you confuse right and left when giving directions?	4	3	2	1	0
5.	Do you bump into people?	4	3	2	1	0
6.	Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
7.	Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0
8.	Do you say something and realize afterwards that it might be taken as insulting?	4	3	2	1	0
9.	Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
10.	Do you lose your temper and regret it?	4	3	2	1	0
11.	Do you leave important letters unanswered for days?	4	3	2	1	0
12.	Do you find you forget which way to turn on a road you know well but rarely use?	4	3	2	1	0
13.	Do you fail to see what you want in a supermarket (although it's there)?	4	3	2	1	0
14.	Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0
15.	Do you have trouble making up	4	3	2	1	0

	your mind?					
16.	Do you find you forget appointments?	4	3	2	1	0
17.	Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
18.	Do you find you accidentally throw away the thing you want and keep what you meant to throw away – as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
19.	Do you daydream when you ought to be listening to something?	4	3	2	1	0
20.	Do you find you forget people's names?	4	3	2	1	0
21.	Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
22.	Do you find you can't quite remember something although it's "on the tip of your tongue"?	4	3	2	1	0
23.	Do you find you forget what you came to the shops to buy?	4	3	2	1	0
24.	Do you drop things?	4	3	2	1	0
25.	Do you find you can't think of anything to say?	4	3	2	1	0

Attention-Related Cognitive Errors Scale

The following statements are about minor mistakes and absent-mindedness everyone notices from time to time, but we have very little information about just how common they are. The great majority of time these little foibles are harmless, though they do have serious safety implications in industry and everyday life. We want to know how frequently these sorts of things have happened to you.

There are 12 questions. Please answer by circling a number on the scale provided below each question.

1.I have gone to the fridge to get one thing (e.g., milk) and taken something else (e.g., juice).				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

2. I go into a room to do one thing (e..g, brush my teeth) and end up doing something else (e.g., brush my hair).				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

3. I have lost track of a conversation because I zoned out when someone else was talking.				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

4. I have absent-mindedly place things in unintended locations (e.g., putting milk in the pantry or sugar in the fridge).				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

5. I have gone into a room to get something, got distracted, and wondered what I went there for.				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

6. I begin one task and get distracted into doing something else.				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

7. When reading, I find that I have read several paragraphs without being able to recall what I read.				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

8. I make mistakes because I am doing one thing and thinking about another.				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

9. I have absent-mindedly mixed up targets of my action (e.g., pouring or putting something into the wrong container).				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

10. I have to go back and check whether I have done something or not (e.g., turning out lights, locking doors).				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

11. I have absent-mindedly misplaced frequently used objects such as keys, pens, glasses, etc.				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

12. I fail to see what I am looking for even though I am looking right at it.				
Never	Rarely	Sometimes	Often	Very often
1	2	3	4	5

Cognitive and Affective Mindfulness Scale - Revised

The following statements are about minor mistakes and absent-mindedness everyone notices from time to time, but we have very little information about just how common they are. The great majority of time these little foibles are harmless, though they do have serious safety implications in industry and everyday life. We want to know how frequently these sorts of things have happened to you.

There are 12 questions. Please answer by circling a number on the scale provided below each question.

1. It is easy for me to concentrate on what I am doing.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

2. I am preoccupied by the future.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

3. I can tolerate emotional pain.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

4. I can accept things I cannot change.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

5. I can usually describe how I feel at the moment in considerable detail.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

6. I am easily distracted.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

7. I am preoccupied by the past.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

8. It’s easy for me to keep track of my thoughts and feelings.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

9. I try to notice my thoughts without judging them.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

10. I am able to accept the thoughts and feelings I have.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

11. I am able to focus on the present moment.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

12. I am able to pay close attention to one thing for a long period of time.				
Rarely	Sometimes	Often	Almost Always	Always
1	2	3	4	5

Need for Cognition

Write in the number that best fits your view:

1	2	3	4
completely false	mostly false	mostly true	completely true

_____1. I would prefer complex to simple problems.
_____2. I like to have the responsibility of handling a situation that requires a lot of thinking.
_____3. Thinking is not my idea of fun.
_____4. I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.
_____5. I try to anticipate and avoid situations where there is likely chance I will have to think in depth about something.
_____6. I find satisfaction in deliberating hard and for long hours.
_____7. I only think as hard as I have to.
_____8. I prefer to think about small, daily projects to long-term ones.
_____9. I like tasks that require little thought once I've learned them.
_____10. The idea of relying on thought to make my way to the top appeals to me.
_____11. I really enjoy a task that involves coming up with new solutions to problems.
_____12. Learning new ways to think doesn't excite me very much.
_____13. I prefer my life to be filled with puzzles that I must solve.
_____14. The notion of thinking abstractly is appealing to me.
_____15. I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
_____16. I feel relief rather than satisfaction after completing a task that required a lot of mental effort.
_____17. It's enough for me that something gets the job done; I don't care how or why it works.
_____18. I usually end up deliberating about issues even when they do not affect me personally.

Cognitive Reflection Test

A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?

Answer: ____________

If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?

Answer: ____________

In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?

Answer: ____________

Barratt Impulsiveness Scale

People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Read each statement and circle the appropriate number based on the scale below. Do not spend too much time on any statement. Answer quickly and honestly

Rarely/Never	Occasionally	Often	Almost Always or Always
1	2	3	4

1 I plan tasks carefully.	1	2	3	4
2 I do things without thinking.	1	2	3	4
3 I make-up my mind quickly.	1	2	3	4
4 I am happy-go-lucky.	1	2	3	4
5 I don’t “pay attention.”	1	2	3	4
6 I have “racing” thoughts.	1	2	3	4
7 I plan trips well ahead of time.	1	2	3	4
8 I am self controlled.	1	2	3	4
9 I concentrate easily.	1	2	3	4
10 I save regularly.	1	2	3	4
11 I “squirm” at plays or lectures.	1	2	3	4
12 I am a careful thinker.	1	2	3	4
13 I plan for job security.	1	2	3	4
14 I say things without thinking.	1	2	3	4
15 I like to think about complex problems.	1	2	3	4
16 I change jobs.	1	2	3	4
17 I act “on impulse.”	1	2	3	4
18 I get easily bored when solving thought problems.	1	2	3	4
19 I act on the spur of the moment.	1	2	3	4
20 I am a steady thinker.	1	2	3	4
21 I change residences.	1	2	3	4
22 I buy things on impulse.	1	2	3	4
23 I can only think about one thing at a time.	1	2	3	4
24 I change hobbies.	1	2	3	4
25 I spend or charge more than I earn.	1	2	3	4

26 I often have extraneous thoughts when thinking.	1	2	3	4
27 I am more interested in the present than the future.	1	2	3	4
28 I am restless at the theater or lectures.	1	2	3	4
29 I like puzzles.	1	2	3	4
30 I am future oriented.	1	2	3	4

Boredom Proneness Scale

There are 28 statements below. Please indicate the degree to which each statement describes you by circling a number on the scale provided below each question.

1. It is easy for me to concentrate on my activities.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

2. Frequently when I am working, I find myself worrying about other things.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

3. Time always seems to be passing slowly.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

4. I often find myself at "loose ends", not knowing what to do.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

5. I am often trapped in situations where I have to do meaningless things.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

6. Having to look at someone's home movies or travel slides bores me tremendously.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

7. I have projects in mind all the time, things to do.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

8. I find it easy to entertain myself						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

9. Many things I have to do are repetitive and monotonous.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

10. It takes more stimulation to get me going than most people.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

11. I get a kick out of most things I do.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

12. I am seldom excited about my work.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

13. In any situation I can usually find something to do or see to keep me interested.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

14. Much of the time, I just sit around doing nothing.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

15. I am good at waiting patiently.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

16. I often find myself with nothing to do, time on my hands.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

17. In situations where I have to wait, such as a line, I get very restless.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

18. I often wake up with a new idea.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

19. It would be very hard for me to find a job that is exciting enough.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

20. I would like more challenging things to do in life.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

21. I feel that I am working below my abilities most of the time.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

22. Many people would say that I am a creative or imaginative person.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

23. I have so many interests, I don’t have time to do everything.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

24. Among my friends, I am the one who keeps doing something the longest.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

25. Unless I am doing something exciting, even dangerous, I feel half-dead and dull.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

26. It takes a lot of change and variety to keep me really happy.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

27. It seems that the same things are on television or the movies all the time; it's getting old.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

28. When I was young, I was often in monotonous and tiresome situations.						
Strongly Disagree			Neither agree nor disagree			Strongly Agree
1	2	3	4	5	6	7

Media Multi-tasking Index

On average, how many hours a week do you spend using each of the following media?

Print media (e.g., newspaper)		Telephone/cell phone voice calls	
Television		Instant messaging	
Computer-based video (Youtube)		Text-messaging	
Music		Email	
Non-music Audio		Web surfing	
Video/computer games		Computer applications (e.g., Word)	

Using the scale, indicate to what degree you use the media listed in the column while primarily using the each medium listed in the rows.

0 = Never | 1 = A little of the time | 2 = Some of the time | 3 = Most of the time

	Print Media	Television	Computer-based Video	Music	Non-music Audio	Vide/Computer games	Phone/cellphone voice calls	Instant messaging	Text-messaging	Email	Web surfing	Computer Applications
Print media												
Television												
Computer-based video												
Music												
Non-music Audio												
Video/computer games												
Phone/cell voice calls												
Instant messaging												
Text-messaging												
Email												
Web surfing												
Computer applications												

Demographics Questionnaire

Below are some general questions about you. Read each question and write your response in the blank or circle the most appropriate response on the list.

1. Age: _______ years

2. Sex: ____________

3. University Major __________________

4. University average grade: _____%

5. Primary spoken/written language (circle)
   English
   French
   Spanish
   Other: __________________

6. Political Orientation (circle)
   Very liberal
   Liberal
   Moderate
   Conservative
   Very conservative

7. Which of the following best describes the area you grew up? (circle)
   Urban
   Suburban
   Rural

8. Did you drink a caffeinated beverage today? (circle)

   Yes/no

   If yes, how long ago? _____ hours

   If yes, what size was the drink? _______________________

9. Approximately how many hours of sleep to you get on a typical night?

   _________ hours

10. Approximately how many hours of sleep did you get **last night**? (circle)

__________ hours

11. Do you feel that you regularly get enough sleep **each night**? (circle)

Yes/No

12. Do you take any medications to help you sleep? (circle)

Yes/No

13. How many days per week do you exercise for at least 20 minutes?

0 1 2 3 4 5 6 7

14. In your estimation, do you eat a well-balanced diet?

Yes/No

15. Do you smoke? (circle)

Yes/No

16. Approximately how many cigarettes do you smoke per day?

_______ per day

17. How long ago did you have a cigarette?

_____________ hours

18. Have you ever thought that you might have Attention Deficit Disorder? (circle)

Yes/No

19. Has anyone suggested that you might have Attention Deficit Disorder? (circle)

Yes/No

20. Have you ever been prescribed medication for Attention Deficit Disorder? (circle)

Yes/No

21. If yes, did it work? (circle)

Yes/No

22. Have you ever sustained trauma to the head that was sufficient to produce an altered state of consciousness? e.g. feeling dazed, dizzy or confused.

    Yes/No

23. If yes, how many times has this happened? ___________

24. How long ago was the most recent (or only) occurrence?

    ______________________________ (approximately)

25. Have you ever sustained trauma to the head that was sufficient to produce a **loss** of consciousness? e.g., blacked out.

26. If yes, how many times has this happened? ___________

27. When was the most recent (or only) occurrence?

    _____________________ (approximate date)

28. How many hours per week do you play video games (can include consoles, PCs, or tablets/phones)?

    __________ hours

29. Read the below list of video game categories and rank them in terms of how often you play. You would write a “1” for the most often played category, followed by a “2” for the next most-often played category. Leave blank if you do not play video games from that category.

    __Action/Adventure
    __First Person Shooter
    __Simulation
    __Racing/Driving
    __Strategy
    __Arcade Fighting
    __Other (______________)

Chapter 5

Self-reported mind-wandering predicts moment-to-moment attention capture

Introduction

We like to think that we always have control over what our attention does. We know that attention can be directed voluntarily based on our own goals as this is one of the basic requirements for successful daily functioning. However, just as our attention can be voluntarily directed by our goals, it can also be involuntarily captured by personally relevant or highly salient stimuli. The focus of the present paper is involuntary attention capture.

Involuntary attention capture can be characterized in two ways. One in which involuntary capture is driven by stimulus salience alone. Any sufficiently salient stimuli such as sudden onsets or offsets, a flash of light, or a colour singleton can capture attention irrespective of the nature of the task, the to-be-attended target, or the viewer's intentions (Burnham, 2007; Hickey, McDonald, & Theeuwes, 2006; Rauschenberger, 2003; Schreij, Theeuwes, & Olivers, 2010; Theeuwes, 1991, 1992, 1994, 2004, 2010; Yantis & Jonides, 1984). Even when such distractors are known to be uninformative in terms of the perceiver's task, they can nonetheless capture attention. For example, task-irrelevant abrupt onset stimuli are known to capture attention even when they are completely irrelevant to the task and they never predict the location of a subsequent target (Remington, Johnston, & Yantis, 1992). Based on these findings, one view of attention capture argues that the capacity for a stimulus to capture attention does not depend on whether that stimulus matches the individual's attentional search set. This form of attention capture, driven by stimulus salience alone, is known as non-contingent capture (e.g., Theeuwes, 1994).

The non-contingent capture viewpoint was disputed by Folk and colleagues (Folk, Remington, & Johnston, 1992; see also Gibson & Kelsey, 1998) who found that abrupt onsets would only capture attention if the viewer was also looking for targets that were defined by an abrupt onset. This contrasting contingent attention capture viewpoint (see also Leber & Egeth, 2006; Yantis & Jonides, 1984, 1990) suggests that attention capture is not driven by stimulus salience alone but instead depends on the individual's search parameters. That is, the capacity of a task-irrelevant stimulus to capture attention depends largely on a participant's subjective salience of that stimulus. It could be the case that the task-irrelevant stimulus is personally meaningful to the participant or that one of the features of the task-irrelevant stimulus matches a feature of the target stimulus. To the extent that a participant is using one or more features of the task-irrelevant stimulus as part of their search set for a target stimulus, the task-irrelevant stimulus can capture attention. For example, when a participant is looking for a green circle, other green objects in the search array are more likely to be processed and subsequently capture attention. According to this viewpoint, capture by a stimulus is contingent on that stimulus matching some parameter of the individual's search set, and is therefore known as contingent capture (e.g., Folk et al., 1992).

As described in previous chapters, attention capture has been found to be a reliable individual difference trait both within a single testing session (Chapter 3 herein, Kawahara & Kihara, 2011) and over the span of one week (see Chapter 3). But, previous studies examining individual difference predictors of involuntary attention capture have shown that it is difficult to predict an individual's overall magnitude of capture in a task. Working memory capacity has been shown to be related to the ability to achieve goals despite distracting task-irrelevant stimuli (Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2002, 2003) in the auditory (Conway, Cowan, & Bunting, 2001) and visual domains (e.g., Arnell & Stubitz, 2010; Vogel, McCollough, & Machizawa, 2005) where individuals with low working memory capacity show poor filtering efficiency and an increased propensity to process task-irrelevant material.

However, Chapter 4 found that working memory capacity, as assessed using the OPSAN task, was not related to capture in (non-) contingent visual search tasks, nor were a variety of self-report measures of attentional control and cognitive functioning. Forster and Lavie (2014) found that self-reported Daydreaming Frequency was associated with distraction by task-irrelevant (but not task-relevant) stimuli. But this finding was based on the use of highly salient and personally relevant distractor stimuli. Chapter 4 showed that the self-reported general propensity to mind-wander did not predict in-task attention capture but did predict other self-report measures of attentional distraction.

These null results suggest that attention capture may instead be better characterized by state effects such as participants' mental state. Mental state could be driven by environmental factors such as the amount of sleep a participant had the night before testing, by recent caffeine consumption, or how anxious they are during testing. However, Chapter 3 showed moderate test-retest reliability for each of the capture measures, and that these reliability estimates across testing sessions were comparable to corrected split-half (odd/even) reliability estimates calculated within session. These findings suggest that state effects that vary from one testing session to another did not have much impact on attention capture estimates. However, individual differences in the ability to stay focused on task goals not only vary across laboratory testing sessions, but also vary trial to trial within a given session. Spontaneous mind-wandering is common in daily life and when performing computerized cognitive tasks in the lab (McVay & Kane, 2010). Indeed, adults spend a third to nearly half of their waking life thinking about something other than their immediate goals (Kane et al., 2007; Killingsworth & Gilbert, 2010; McVay & Kane, 2009). The involuntary drifting of your thoughts away from your immediate goals, known as mind-wandering or task-unrelated thoughts, can be pleasant but can also lead to mistakes in your current task. You may read through an entire paragraph only to realize at the end that your thoughts had been elsewhere and you do not actually remember any of its content. Such effects on reading comprehension are well documented (e.g., Kane & McVay, 2012), but the effects of mind-wandering are not limited to reading comprehension. They can also manifest in quantifiable laboratory contexts where it is associated with increased errors in vigilance in speeded response tasks (e.g., go/no-go tasks; Kane & McVay, 2012) and with general susceptibility to distraction (Forster & Lavie, 2014). Thus, mind-wandering would appear to be an ideal predictor of trial-to-trial involuntary attention capture.

Mind-wandering is thought to reflect default mode network activation (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Killingsworth & Gilbert, 2010). The so-called default mode network (DMN) includes brain regions that show strong functional overlap and tend to activate when no other externally oriented processes are active. It includes areas that are predominately parietally located and is considered to reflect an idle state during which internal or introspective thoughts can rapidly enter and exit consciousness (Smallwood, Brown, Baird, & Schooler, 2012). When attention is focused on task goals in the external environment, the DMN is deactivated and the executive network is brought online to meet the demands of the task. Activation of the DMN and the executive network is thought to be mutually exclusive such that when one network is active, the other is suppressed (e.g., Fox et al., 2005; Greicius, Krasnow, Reiss, & Menon, 2003). DMN activity has been linked with mind-wandering episodes across a variety of studies suggesting that mind-wandering may represent a decoupling of attentional resources from the demands of the task. Typically, such a pattern emerges when tasks demands are perceived to be low or during tasks that are well-practiced (e.g., Baird et al., 2012; Mason et al., 2007; Schooler et al., 2011). However, there is some evidence for simultaneous recruitment of both the default and executive network during mind-wandering (Christoff et al., 2009), where such a decoupling of attention from the external world and a redirection to internal thought (Smallwood & Schooler, 2006) argues for a dynamic reallocation of attention from the primary task and towards the maintenance of internal thought (Smallwood et al., 2012). However, this perspective has been met with some criticism arguing that mind-wandering reflects a failure of executive processes (e.g., Barron, Riby, Greer, & Smallwood, 2011; McVay & Kane, 2010). Whether one adopts the executive recruitment or the executive failure viewpoint, it stands to reason that during a mind-wandering episode the executive network is not processing external stimuli and adapting to task demands.

Given that mind-wandering is thought to be related to DMN activation and, arguably, misdirected engagement of executive control networks away from external stimuli, it is possible that mind-wandering might affect the deployment of attention settings. The development and maintenance of an effective search strategy or attentional set prioritises certain stimuli or features of stimuli for more efficient search (e.g., prioritizing green items when searching for a green target). Use of a search set helps to avoid needless processing of material that is irrelevant to task goals (Folk, Remington, & Johnston, 1992; Leber & Egeth, 2006; Theeuwes, 2004). This process requires attentional resources as the search set is actively maintained by prefrontal executive control regions, and its use is regulated by areas such, the anterior cingulate cortex which is thought to modulate cognitive resources for goal-relevant control of behavior (e.g., Bush, Luu, & Posner, 2000). If attentional control resources are occupied by mind-wandering, then task performance is likely to suffer as a result of less goal-directed processing of the display. The use of non-contingent and contingent tasks allows me to make separate and unique predictions for the impact mind-wandering may have on the development and maintenance of attentional sets and the subsequent behavioural costs.

First of all, mind-wandering may simply reflect a general failure of executive control (Kane & McVay, 2012; McVay & Kane, 2009, 2010) and could lead to slower performance or impaired ability to complete the task overall (but see Forster & Lavie, 2014). In addition, the effect of mind-wandering on capture may also be more nuanced. If mind-wandering disrupts executive processes, and executive processes are required to build and maintain an effective search set, filtering task-irrelevant distractors from target stimuli may be less efficient. Thus, in a non-contingent visual search task, one would expect that during a mind-wandering episode where distractors share no features with targets, distractors may be more likely to be processed compared to when mind-wandering is not occurring. For example, if a participant is not mind-wandering and his search set is strongly enforcing search for circles, then he may be able to effectively ignore distractors, even those that are salient, as long as they are not circles. On the other hand, if a participant is mind-wandering and his search set is not strongly enforcing search for target circles, then he may default to attending to any item randomly, or attend in a bottom-up manner to the most salient item in the display – perhaps a green square amongst red shapes. If so, then non-contingent capture costs should be greater when participants report being unfocused on the task than when they report being focused on the task.

In contrast, capture in a contingent visual search task depends on the use of an attentional set that includes the feature shared between targets and distractors (e.g., when looking for a green circle target, a green square may capture attention in a display of red squares). In this version of visual search, capture occurs only if a feature of the distractor matches a feature of the target. If mind-wandering disrupts the development and maintenance of an attentional set, then less (or equal) capture cost might be expected if participants report being unfocused on the task, relative to when they report being focused on the task. For example, if a participant is searching for a red circle amongst green squares and an occasional red square distractor, then equal capture would be expected under mind-wandering present and absent conditions if search defaults to being driven by bottom-up salience. This is because both red items will be both salient (attracting bottom-up attention) and match the search set (attracting top-down attention). However, if mind-wandering also causes an increase in attending to random display items, then capture may actually be reduced in the contingent search condition as the red square would only have a particular ability to attract attention when the search set was activated. Overall, mind-wandering, versus being focused on the task, was expected to increase capture costs in the non-contingent visual search task, but decrease or show no effect on cost in the contingent visual search task.

These hypotheses are tested in the context of two variations of a well-known visual search task: one, a non-contingent version, where task-irrelevant stimuli capture attention simply due to their visual salience (e.g., a green distractor in a field of red stimuli including a red target); and the other, a contingent version, where non-target stimuli match one of two target-defining features (e.g., a green square distractor in a field of red squares and a green circle target) (Theeuwes, 1994). In each task, participants will periodically be asked to report whether they were just on-task or off-task, and their reports will be used to group the two trials previously completed into mind-wandering and no mind-wandering bins. Capture will then be examined separately for each combination of capture task and mind-wandering condition. A dispositional measure of spontaneous and deliberate mind-wandering will also be examined so that both trial-level and individual-level relationships with mind-wandering can be investigated in the same study.

Methods

Participants

As part of the same study reported in Chapter 4, 129 undergraduate students (114 female) at Brock University participated in exchange for research hours for a course. Mean age was 19.86 years with a range of 18 to 41 years of age. All participants reported normal or corrected-to-normal visual acuity and no colour blindness. A total of four participants were eliminated from further analysis because they did not complete both tasks

Design & Procedure

All stimuli were shown and all responses were collected via a Dell desktop computer running E-Prime v1.1 (Schneider, Eschman, & Zuccolotto, 2002) and responses were made using the Dell desktop computer keyboard. Participants completed contingent spatial visual search task followed by the non-contingent version. The tasks were separated by a 10 minute computer-based task that was not part of the present study.

Contingent Spatial Visual Search Task

Parameters for the Spatial Visual Search task were based on the task as described in Theeuwes (1994). Stimuli were comprised of 5 or 7 items presented in a circular array displayed in the centre of the screen. The diameter of this invisible circle subtended 6.4° of visual angle. Target stimuli were vertical and horizontal lines 0.7° of visual angle long contained inside a circle subtending 1.6° of visual angle. Non-target stimuli were comprised of black lines 0.7° of visual angle long rotated 22.5° from vertical or horizontal contained within a square subtending 1.6° of visual angle. See Figure 5-1 Panel A for an illustration of stimuli.

Each trial began with the presentation of a small black fixation dot in the centre of screen subtending a visual angle of 0.3° presented for 250ms. This dot then expanded to 0.6° of visual angle for 600ms to warn participants and then contracted back to 0.3° of visual angle for a jittered duration (100ms, 200ms, 400ms, 600ms, 800ms, or 1000ms determined randomly on each trial). Following a 300ms blank ISI, a search array was presented in which one target and 4 or 6 non-target items were displayed. This array remained on screen until participants indicated whether the target line was vertical or horizontal with a key press. Target location in the array was determined randomly for each trial. Following participants' response a blank ISI (jittered as above) preceded the onset of the fixation dot for the next trial.

In the contingent visual search task, target lines were always presented inside a green circle and non-targets were always presented inside squares. In the distractor-absent condition (half of trials), all non-targets were presented in red squares; in the distractor-present condition (half of trials), one of the non-targets, selected at random, was contained inside a green square. All stimuli were presented against a gray background. Distractor-present and -absent trials were equally distributed among set sizes of 5 and 7. All trials were intermixed within a given experimental block. Participants indicated the orientation of the target line (vertical or horizontal) with a key press as quickly and as accurately as possible. Response time and accuracy were collected.

In this task, targets were defined as always being contained inside a green circle. Thus, targets presented amongst an array of red squares were expected to be relatively easy to detect and identify. In contrast, targets presented during the distractor-present condition, with a single green square, should be more difficult to detect and identify quickly. In addition to the feature of shape, the search feature of colour green is an effective filtering strategy and thus, non-target items that share this feature with targets are more likely to capture attention. Thus, capture in this task is contingent to the extent to which an attentional set for the colour green has been developed. Capture in this task is defined as the difference in response time means for distractor-present and distractor-absent conditions. Relatively higher response time (RT) differences are considered to reflect greater capture.

Mind-wandering probes were distributed evenly throughout the task. Probes were presented onscreen and asked participants, “During the last trial, were your thoughts completely ON TASK?” to which participants responded with a key press indicating “yes, on task” (press the 1 key) or “no, not on task” (press the 0 key). Responses to probes were not timed. Mind-wandering probes were presented, on average, every 16 trials throughout the duration of the task. Given the jitter of the stimulus presentation duration and variance in participant response times on a trial by trial basis, probes were presented approximately every 45 seconds. A total of 18 mind-wandering probes were presented to each participant.

Non-Contingent Spatial Visual Search

All stimuli and timing were identical to the Contingent Visual Search task described above, but with one critical difference. Participants were instructed that black target lines (vertical or horizontal) would appear inside a circle regardless of the circle’s colour. That is, targets could appear inside a red circle or inside a green circle. See Figure 5-1 Panel B for an illustration.

In this task, targets were defined as always being contained inside a circle regardless of its colour. Thus, only container shape (e.g., square versus circle) could be used as a reliable search filter. Colour was not a reliable predictor of target location. In this way, targets and distractors shared no features with each other—capture by distractors was not contingent on the development of an attentional set for colour. Furthermore, capture by non-target colour singletons may reflect unnecessary processing of irrelevant content. Capture in this task is defined as the difference in response time means for distractor-present and distractor-absent conditions. Relatively higher RT differences are considered to reflect greater capture.

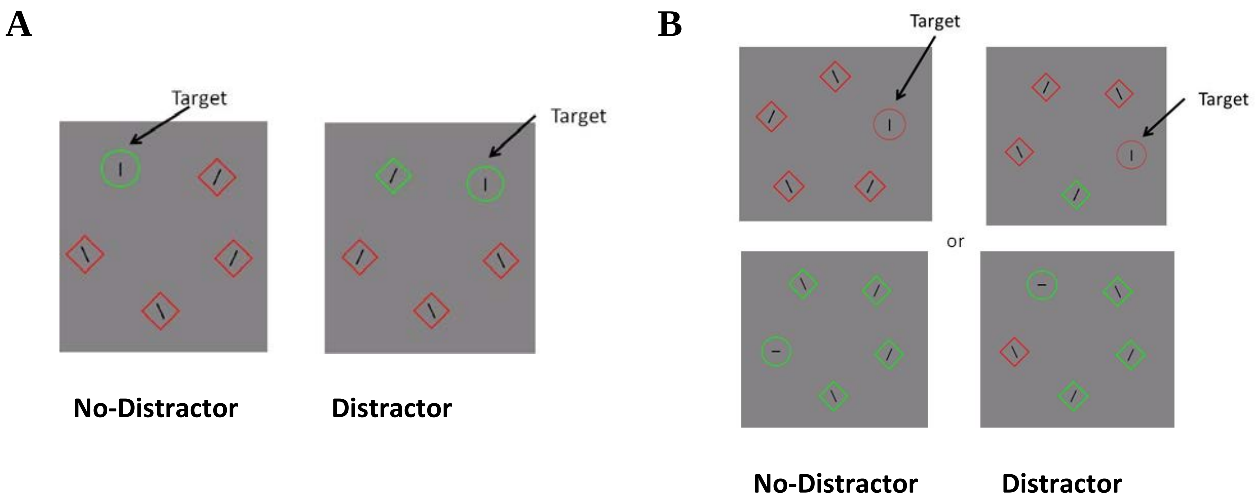

Figure 5-1. Illustration of stimuli from each task. Panel A shows stimuli from the Contingent Visual Search task. Panel B shows stimuli from the Non-Contingent Visual Search task.

Data Analyses

Response Times were included in analyses only if the correct target identification was made. Individual participant RTs were also subjected to an outlier removal procedure that removed RTs that fell beyond +/- 3 standard deviations from their individual mean RT in each condition of the 2 (Task: Non-contingent vs Contingent) by 2 (Distractor: Present vs Absent) by 2 (Report Mind-wandering: Yes vs No) design. Data from two participants were removed as their mean costs fell beyond +/- 3 standard deviations of the group mean. The final sample size for the present analyses was 125 (110 female) with a mean age of 20.04 years.

A note on sample sizes

Given that only 18 mind-wandering probes were presented to participants and they were presented randomly on distractor-present and distractor-absent conditions in each task, there was a need to ensure that a sufficient number of RTs were entered into each cell of the 2x2. Thus, RTs were included for the two trials immediately preceding each mind-wandering probe. This increased the number of trials entered into the analysis for each combination of task variables and had the effect of extending the timeframe for inclusion to approximately two seconds prior to each mind-wandering probe. You will also notice that the degrees of freedom vary between tasks and from analysis to analysis. This is due to the way in which the mind-wandering probes were administered within each task. To ensure that the nature of each attention capture task was not altered by the addition of periodic mind-wandering probes, probes were presented randomly every 16 trials regardless of the trial type. Thus, it is possible that, by chance, some participants received more mind-wandering probes on distractor-present trials than on distractor-absent trials, or vice-versa. This pattern was compounded by the observation that some participants report mind-wandering more often than others and that on average, participants reported mind-wandering on more than half of the probes. Thus, comparisons made between trials on which mind-wandering was reported and trials on which participants reported being focused on the task may differ in terms of the number of trials included in the test. Because ANOVA analyses rely on listwise deletion when an empty data cell is encountered, all mind-wandering analyses include participants only if all four cells contain data. The listwise deletion procedure produced a final sample size of n = 103 for the non-contingent search tasks, and of n = 90 for the contingent search task.

Results

The expected pattern of capture was observed in each task whereby distractor-present RTs were significantly longer than distractor-absent RTs in both non-contingent, $t(124) = 12.16$, $p < .001$, $d = .58$, and the contingent spatial search tasks, $t(123) = 14.25$, $p < .001$, $d = .41$. Thus, participants appeared to be completing the tasks in the intended way. This pattern was also observed overall when examining only the subset of participants included in the mind-wandering analyses for both the non-contingent, $t(102) = 11.48$, $p < .001$, $d = .38$, and contingent, $t(89) = 12.78$, $p < .001$, $d = .39$, search tasks. As before, distractor cost (capture) for the two tasks was not correlated, $r(121) = .07$, $p = .406$.

In the contingent spatial search task, participants reported mind-wandering on 68% (SD = .29) of probes. In the non-contingent spatial search task, participants reported mind-wandering on 66% of probes (SD = .27). This difference was not significant, $t\ (124) = 1.56$, $p = .121$. This rate of reported mind-wandering is approximately in line with the pattern observed by Seli and colleagues (Seli, Carriere, Levene, & Smilek, 2013) who found that mind-wandering probes presented every 30 seconds yielded a mind-wandering report rate of approximately 46% whereas a longer intervals between probes (e.g., two or three minutes) yielded much higher reports of mind-wandering in the range of 80% of probes. Our presentation rate was approximately 45 seconds between probes and thereby yielded a mind-wandering rate in the expected range.

The proportion of trials on which participants reported mind-wandering was highly correlated between tasks over all participants, $r(124) = .80$, $p < .001$, and when analyzing only the subset of participants included in the mind-wandering analysis, $r(90) = .72$, $p < .001$, suggesting that individuals who tend to mind-wander more in one task, also tend to mind-wander more in the other task. Thus, individuals can be characterized by their natural tendency to mind-wander. However, an individual's overall proportion of mind-wandering in the experiment did not predict overall distractor cost in either the non-contingent, $r(122) = .10$, $p = .243$, or the contingent version, $r(124) = -.03$, $p = .698$. The same pattern held when including only the trials on which mind-wandering was reported in both the non-contingent, $r(120) = -.04$, $p = .611$, and the contingent task, $r(118) = .12$, $p = .229$. Additionally, self-reported dispositional spontaneous mind-wandering scores on the questionnaire did not predict capture in either the non-contingent, $r(122) = -.06$, $p = .462$, or the contingent task, $r(124) = .01$, $p = .905$. Self-reported dispositional spontaneous mind-wandering also did not predict the overall proportion of mind-wandering in either the non-contingent, $r(122) = .09$, $p = .318$, or the contingent task, $r(124) = .00$, $p = .992$.

A 2x2x2 ANOVA with capture task (non-contingent vs. contingent), distractor (present vs. absent), and mind-wandering (yes vs. no) entered as factors, was conducted to examine whether the capture effects changed as a function of trial-to-trial mind-wandering. The results showed a significant main effect of distractor, $F(1, 73) = 53.76$, $p < .001$, $\eta_p^2 = .42$ where RTs were longer overall for trials where a distractor was present than on no-distractor trials. A significant overall main effect of mind-wandering was also observed where RTs were longer overall on trials where participants reported mind-wandering than when they reported being on-task, $F(1, 73) = 23.30$, $p < .001$, $\eta_p^2 = .24$. A main effect of Task was also observed where RTs were longer overall in the non-contingent task than in the contingent task, $F(1, 73) = 70.49$, $p < .001$, $\eta_p^2 = .49$. No significant two-way interactions were observed. However, a three-way interaction between task, distractor condition, and mind-wandering reports was significant, $F(1, 73) = 3.86$, $p = .05$, $\eta_p^2 = .05$ reflecting the greater modulation of capture (i.e, the difference between distractor-present and distractor-absent conditions) by mind-wandering in the non-contingent task than in the contingent task. That is, distractors showed a greater RT cost when participants reported mind-wandering, but only in the non-contingent task. See Figure 5-2 for means.

To unpack this 3-way interaction, individual 2x2 ANOVAs were then conducted separately for each task. In the non-contingent version, a main effect was observed for distractor condition, $F(1, 102) = 22.21$, $p < .001$, $\eta_p^2 = .18$, and for mind-wandering, $F(1, 102) = 14.88$, $p < .001$, $\eta_p^2 = .13$. Capture was observed whether participants reported mind-wandering, $t(102) = 5.50$, $p < .001$, $d = .43$, or reported being focused on the task, $t(102) = 2.34$, $p = .021$, $d = .20$. The analysis also revealed a significant Distractor x Mind-Wandering interaction, $F(1, 102) = 4.73$, $p = .032$, $\eta_p^2 = .05$ where the cost of the distractor was larger when participants reported mind-wandering compared to when they reported being focused on the task, $d = .42$.

The same analysis conducted on the contingent version of the task again revealed a significant main effect for both distractor condition, $F(1, 89) = 17.17$, $p < .001$, $\eta_p^2 = .16$, and for mind-wandering, $F(1, 89) = 12.99$, $p = .001$, $\eta_p^2 = .13$. Capture was also observed whether participants reported mind-wandering, $t(89) = 2.81$, $p = .006$, $d = .22$, or reported being focused on the task, $t(89) = 2.88$, $p = .005$, $d = .28$. However, in the contingent capture task the Distractor x Mind-Wandering interaction was not significant, $F < 1$. Thus mind-wandering did not have an effect on capture in the contingent spatial search task. Indeed, examination of the means in Figure 5-2 shows that mind-wandering had the opposite numerical effect on capture in the contingent task compared to the non-contingent task. In the contingent capture task the trend was towards less, not more, capture with mind-wandering.

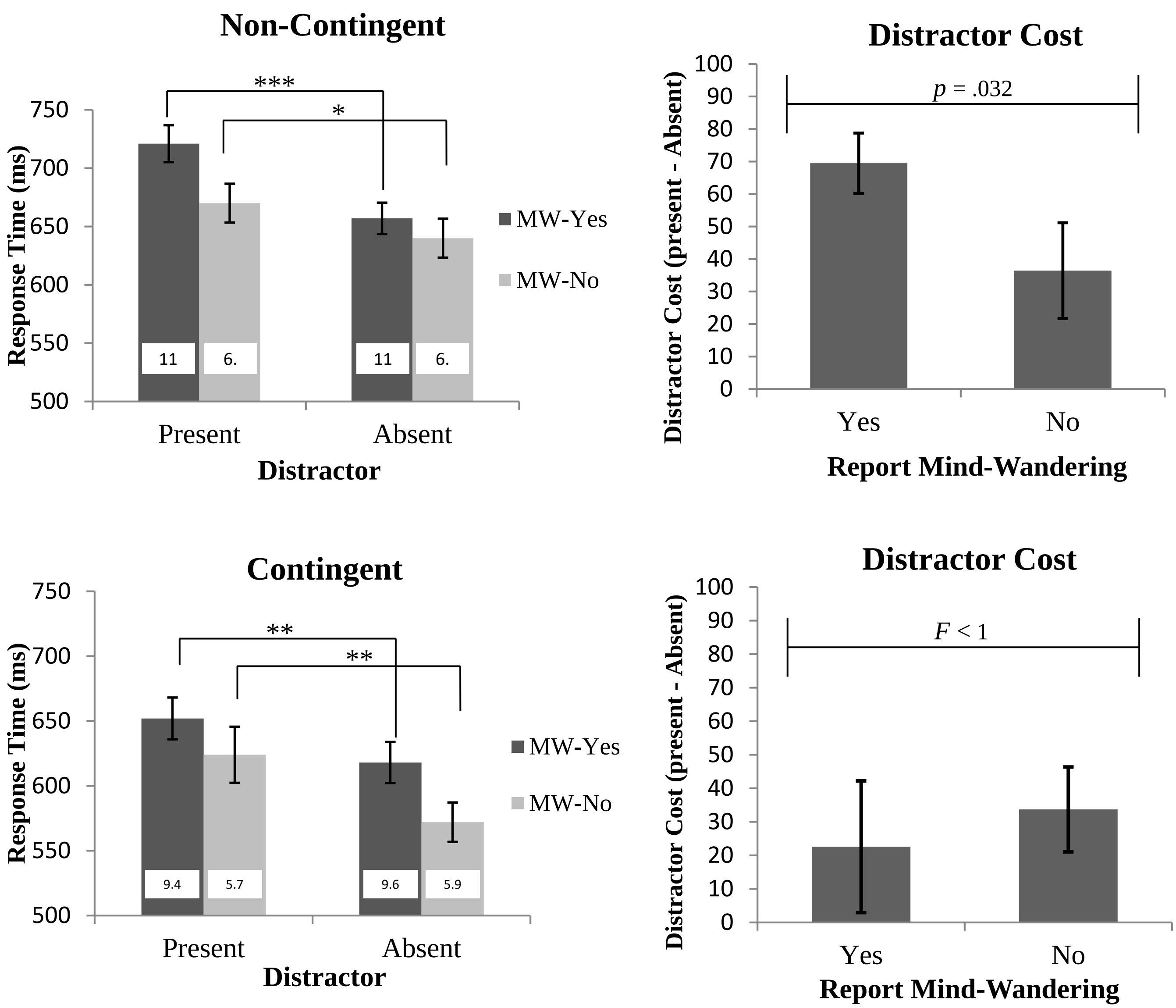

Figure 5-2. Mean response times (ms) as a function of task (non-contingent [top] vs contingent [bottom]), Distractor condition (present vs absent), and self-reported mind-wandering (MW Yes vs No). Error bars represent Standard Error of the mean for each condition. Numbers in white box on each bar represent the average number of data points/trials included for each participant for that mean. Mean distractor cost as a function of mind-wandering is shown to the right. Distractor cost is calculated by subtracting distractor-absent response time from distractor-present response time. Error bars represent the Standard Error of the cost score.

Discussion

The expected pattern of capture was found in both tasks such that the presence of a distractor led to increased response time to identify a target relative to when no distractor was present. This was observed in both the non-contingent and contingent version of a spatial visual search task (Theeuwes, 1994). Attention capture, as measured by the difference in RT for distractor-present and distractor-absent condition, was unrelated for the two tasks. This pattern was previously observed between these and a larger set of capture tasks in Chapters 3 and 4, and it has been difficult to find ways to predict capture in these tasks despite their generally good test-retest reliability.

However, trial-to-trial state effects may also contribute to variance in attention capture. If attention capture is characterized by trial-to-trial state effects, then one limitation of previous efforts to predict attention capture may have been the tendency to correlate overall capture for an individual with other overall capture measures or other individual difference measures. Instead, if one adopts the view that attention capture may be best characterized by moment-to-moment changes in attentional focus, then capture may be predicted by whether participants are performing capture trials while their mind is on-task versus off-task. These moment-to-moment lapses of attention, more commonly referred to as mind-wandering, have been associated with errors in vigilance and an impaired performance on sustained attention tasks (Kane & McVay, 2012; Kane et al., 2007; Killingsworth & Gilbert, 2010; McVay & Kane, 2009).

Mind-wandering was anticipated to impact or modulate attention capture in several ways. First, mind-wandering could have lead to slower performance overall. This pattern was observed in both the non-contingent and contingent visual spatial search tasks where RTs were longer for trials during which mind-wandering was reported compared to trials where mind-wandering was absent. This result fits with other studies that find that mind-wandering, or task-unrelated thoughts, lead to careless performance and a slowing of RTs (Kane & McVay, 2012; McVay & Kane, 2012; Schooler et al., 2011) and suggests that during a mind-wandering episode, individuals may process stimuli inefficiently and fail to initiate timely responses.

However, the moment-to-moment drifting of attention away from the primary task also influenced the way in which critical distractors were processed. Supporting the hypothesis that mind-wandering would impair the ability to inhibit shifts of attention to salient task-irrelevant stimuli (see Kane & McVay, 2012; McVay & Kane, 2009, 2010), attention capture costs were greater in the non-contingent spatial search task when mind-wandering was reported versus when participants reported being on-task. These results are also in accord with the view that mind-wandering can lead to increased default network activation and the misdirection of executive processes away from task-related stimuli (Christoff et al., 2009; Schooler et al., 2011; Smallwood et al., 2012; Smallwood & Schooler, 2006). During such misdirection, the attentional resources needed to build and maintain efficient attentional sets are impaired. In the non-contingent version, failure to maintain an attentional set can lead to increased salience-driven capture.

In contrast, mind-wandering was hypothesized to have no effect on attention capture, or even reduce attention capture, in the contingent capture paradigm where the target and critical distractor shared a salient visual feature that was part of the search-set. Here again the hypothesis was supported in that the results showed no significant differences in distractor costs as a function of mind-wandering. The presence of mind-wandering was associated with a pattern of numerically smaller, but not significantly different, distractor costs than when mind-wandering was absent. The different effects of mind-wandering for contingent and non-contingent capture versions provides evidence that mind-wandering may not have the same effect on attention capture in contingent search as in non-contingent search given that target stimuli are still physically salient in the contingent version of the capture task but not in the non-contingent version of the capture task.

Overall, the pattern of good test-retest reliability of capture, no relationship between capture measures and dispositional mind-wandering, but moment-to-moment modulation of non-contingent attention capture by mind-wandering requires an explanation. The simplest possibility is that individuals are simply poor estimators of their mind-wandering tendencies over the long term, but are good reflectors on whether they are currently mind-wandering. At the very least, there could be a disconnection between meta-awareness of long-term trends and in-the-moment meta-awareness. Further exploration could examine whether moment-to-moment mind-wandering collected over the long-term may yield a better estimate of mind-wandering than a self-report questionnaire that requires participants to provide a retrospective estimate of mind-wandering.

Additionally, performance can be associated with only self-reported mind-wandering. It may be possible that mind-wandering is also occurring on trials during which participants do not report it. Thus, in the present experiment, effects of mind-wandering are expected only so far as participants can accurately gauge their own mental state. Significant differences in capture amounts for mind-wandering yes and no conditions in the non-contingent task, suggests that participants were able to meaningfully classify their mental state at least on a decent proportion of trials.

Forster and Lavie (2014) found a similar pattern where the self-reported general tendency to mind-wander (measured by the Daydreaming Frequency subscale of the Imaginative

Processes Inventory; Singer & Antrobus, 1970) was related to RT costs from task-irrelevant distractors (non-contingent but highly salient) but not related to response congruency effects from task-relevant distractors (contingent). Forster and Lavie (2014) asked participants to identify whether an N or X was presented within a circular array of Os. This array was either presented alone, with a task-irrelevant cartoon character above or below the array, or with a distractor letter to the side of the array that could be either congruent or incongruent with the target identity. Although self-reported mind-wandering predicted capture by the cartoon character, it did not predict the size of the congruency effect observed with irrelevant distractor letters. It is important to note several key differences between their results and the results presented here. Firstly, Forster and Lavie (2014) quantified mind-wandering using a self-report scale of general tendencies to daydream. In the present experiment, an online measure of mind-wandering was used which likely produces a more accurate assessment of focus on the current task and allows for trial to trial variability to be examined. Indeed, the present study showed no relationship between an individual's self-reported tendency to spontaneously mind-wander in daily life when assessed by self-report on the spontaneous mind-wandering questionnaire. Given that trial-to-trial mind-wandering reports interact with the effect size of distraction, but not dispositional mind-wandering, this would seem to be an important distinction.

Secondly, Forester and Lavie used task-irrelevant stimuli that were always highly salient and semantically meaningful stimulus cartoon images presented in a task where participants are visually searching for one of two target letters. These task-relevant and task-irrelevant distractors were presented in the same experimental block. The non-contingent (cartoon images) stimuli were characterized by semantic meaning and greater salience. In a context where distractors are either "exciting" or "boring" the exciting ones are more likely to capture attention and set a precedent for saliency. Finally, cartoon images are comparatively more interesting than judging the orientation of a line and so their use may increase participant engagement in the task thus decreasing the likelihood of mentally drifting away from the task. In contrast, in the present study, irrelevant distractors were always coloured diamonds that were considered contingent or non-contingent based only on differences in the target and its search set.

Individuals who tended to mind-wander in one task also tended to mind-wander in the other as the proportion of trials during which mind-wandering was reported was highly correlated between tasks and there was no difference in the proportion of mind-wandering trials between non-contingent and contingent visual search. Thus, the different effect of mind-wandering on distractor costs in each task is not attributable to different levels of mind-wandering overall. Furthermore, the lack of correlation between the capture costs observed in each task is not attributable to differences in overall mind-wandering proportions (c.f., Forster & Lavie, 2014). It is also important to note that the proportion of mind-wandering did not predict capture in either of the tasks which further reinforces the notion that attention capture is best characterized by moment-to-moment state effects.

Such state effects may be measured using imaging techniques. There is already some evidence for the activation of key default mode network brain regions during mind-wandering. For example, there is evidence that that both the default mode network and the executive network regions were most active when participants were unaware of their own mind-wandering (Christoff et al., 2009) suggesting that it is most pronounced when it lacks meta-awareness.

We could make the assertion that, as a result of increased default network activation during a mind-wandering episode, participants may adopt a more superficial processing style. Such a “lazy” search style could lead to an attentional setting that detects only the most salient stimulus in the visual array. In the case of the non-contingent version, this would always be the colour singleton distractor. This approach would show larger capture during a mind-wandering episode than when participants report being focused on the task and an efficient attentional set is maintained. The same lazy search style in the contingent version would lead to the detection of one colour singleton (target) in the distractor-absent condition which would be easy to locate, but two colour singletons (one target, one critical distractor) in the distractor-present condition. In this way, participants would correctly identify the target on half of the distractor-present trials because half of the time, the first stimulus processed will be the target. This differs from the non-contingent version of the task where colour singletons were always non-targets. Taken together, this suggests that, rather than being immune to the effects of mind-wandering, the task parameters of contingent visual search may simply provide a more forgiving context in which to superficially process stimuli. It may also help explain why capture costs in each task were unrelated to each other. Future studies using neuroimaging techniques during the tasks could explore the possibility that mind-wandering (vis. executive failure) disrupts the ability to form and maintain an attentional set leading to differential performance in contingent and non-contingent attention capture tasks.

The critical contribution of the present chapter is that non-contingent attention capture can be characterized by moment-to-moment lapses of attention rather than purely by stimulus-driven task parameters or other group-level traits. Thus, limiting the prediction of attention capture to group-level differences may ignore a critical aspect of the nature of attention capture. There may be processes engaged moment-to-moment that are not reflected in derived overall capture scores in spatial visual search or other attention capture paradigms.

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Chapter 6

General discussion and conclusion

Summary of Results

Over four studies, some containing multiple experiments, attention capture was explored in a variety of experimental contexts. The over-arching goals were to better understand attention capture at the stimulus level, the group level, the individual differences level, and in terms of moment-to-moment fluctuations in susceptibility to distraction by task-irrelevant stimuli. Below, each of the main findings is discussed in detail, integrating findings and ideas from throughout the thesis and the larger literature.

Finding 1: Semantic Processing of Auditory Distractors is Automatic But Attention Capture Depends on Distractor Significance

Chapter 2 explored the properties of a distractor that allow it to capture attention. Previous research had conceptualized task-irrelevant auditory stimuli as deviants only if they embodied a physical change (e.g., change in pitch, location, or timbre) relative to the prevailing pattern of stimulation (see Parmentier, 2014, for an overview). The detection of such a change signals deployment of attention to the deviant item and results in online performance costs in response time or accuracy (e.g., Berti & Schröger, 2001; Escera, Yago, Corral, Corbera, & Nunez, 2003; Parmentier & Andrés, 2010), as well as offline costs to memory encoding of to-be-remembered material presented at same time as the deviant distractor (e.g., Hughes, Vachon, & Jones, 2007). These findings extend the current literature in terms of what constitutes a deviant, providing evidence that auditory stimuli that are deviant only by virtue of their meaning can also capture attention and impair performance on a primary visual task. Unexpected semantic change can produce a distraction effect provided the semantically deviant stimulus is sufficiently arousing, and that an accompanying physical/acoustic change is not required to induce semantic processing of task-irrelevant stimuli even when they are unrelated to the response set for the primary task. This contrasts with the conclusions of others (Escera et al., 2003; Näätänen, 1992; Parmentier, 2008; Wetzel & Schröger, 2007) who posited that a physical change in the irrelevant auditory stimulus was a necessary antecedent for semantic processing. However, the present results and conclusions are consistent with the more recent theorizing of Parmentier et al. (2014) who posited that semantic processing of auditory deviants reflects two sources, one of which is dependent on prior attention capture as a deviant, and one which is not. Parmentier et al. (2014) drew this conclusion after observing a semantic deviance effect without physical novelty, but under conditions where the deviants were task relevant in that they matched or mismatched the response options for the primary visual task. Here their findings are extended by showing semantic deviants can capture attention even when they are completely unrelated to the primary task.

To be clear, only taboo words captured attention in Study 1; not semantically deviant, but emotionally neutral, words. Some would argue that such a finding is not surprising as taboo words are known to capture attention in a variety of tasks (Aquino & Arnell, 2007; Arnell, Killman, & Fijavz, 2007; MacKay et al., 2004). Note that to recognize that a word is taboo means that one has read the word and accessed its semantic meaning. When emotionally neutral and taboo words are presented randomly as they were here, semantics cannot be accessed for taboo words but not emotionally neutral words because one does not know if a word is taboo or not until semantics have been accessed (i.e., semantic processing must precede categorization as neutral or taboo). Therefore, the results suggest that word meaning is accessed for all irrelevant auditory words, and that both perceptual and meaning information is used to assess the potential value of attending to a deviant auditory stimulus in terms of the need to divert attention.

Indeed, long- and short-term experience with stimuli shapes their significance for attention such that highly salient stimuli associated with reward, fear, or past experience can capture attention even though they do not match current selection goals and are not strictly defined by low-level physical salience. These effects have been observed within the visual modality using paradigms such as visual working memory tasks and visual search. For example, colours previously associated with reward are more likely to be encoded into visual working memory at the expense of neutral-value items (Infanti, Hickey, & Turatto, 2015). Also, value-driven attention capture has been demonstrated in visual search paradigms in that search for a physically salient target is impaired when a physically inconspicuous, irrelevant distractor that was previously associated with monetary rewards is included in the display (e.g., Anderson, Laurent, & Yantis, 2011; Laurent, Hall, Anderson, & Yantis, 2015). The priming of pop-out phenomenon (Maljkovic & Nakayama, 1994) shows that when a visual search target was defined by a feature such as colour or shape, search for the same feature in the next few trials was more efficient. That is, previously rewarded features facilitated search presumably via implicit positive goal-related reward associations (Maljkovic & Nakayama, 2000).

The notion that long- and short-term stimulus valuation can influence allocation of attention could explain why capture in Study 1 was observed for semantically novel taboo auditory words but not semantically novel emotionally neutral auditory words. If we extrapolate the search history beyond the experimental session and into daily life, highly arousing emotional words contain high value information signaling danger or otherwise important information. Through daily experience of their reward value, these arousing items may be flagged for attentional priority. Emotionally neutral semantic deviants, on the other hand, are still processed for meaning, but they may not have been judged as valuable in terms investing additional attentional resources into their processing, thereby not diverting attention away from the primary visual task.

Across the literature on semantic deviants, the pattern of results can be reconciled if one assumes that all irrelevant auditory stimuli are processed for semantic information, but that this information does not influence behaviour unless 1) the stimulus is already being attended by virtue of capturing attention as a physical deviant (Escera et al., 2003; Parmentier, Elsley, Andrés, & Barceló, 2011; Parmentier, Turner, & Perez, 2014; Parmentier, 2008), 2) the stimulus is considered high in value by virtue of its relevance to the current task (e.g., speaking the words "left" or "right" while classifying visual digits as pointing left or right, or 3) the irrelevant auditory information is considered high in value due to its emotionally arousing nature. In this manner, all stimuli are automatically screened for meaning, but attention is only deployed to a deviant semantic stimulus if that meaning is motivationally salient (i.e., contextually or emotionally), or if the stimulus is physically novel.

Finding 2: Semantic Change Detection Evokes RT and Accuracy Costs

I also found that auditory semantic deviants in Study 1 produced costs to both RT and accuracy in the primary visual task. This pattern suggests that when participants are captured by an unexpected highly arousing semantic change, some participants may show only accuracy costs (~21% of the sample) whereas others may show only response time costs (~21% of the sample), while some may show both RT and accuracy costs (~48% of the sample). This may depend on individual differences in cognitive processing styles wherein some participants prioritize speed over accuracy or vice versa, but such individual differences were not examined as part of Study 1. There is some electrophysiological evidence showing that individuals who favour speed over accuracy show greater anticipatory brain activities prior to stimulus onset in a self-paced RT sustained attention task. These same individuals also showed larger N1 amplitudes in response to stimulus presentation (Perri, Berchicci, Spinelli, & Di Russo, 2014) suggesting that greater attentional resources have been allocated to that stimulus location (Luck, Woodman, & Vogel, 2000). Some participants may be more willing to sacrifice speed for accuracy in order to process the unexpected auditory change and this characteristic may be related to individual differences in personality factors. There is some converging evidence to suggest that differences in impulsivity (Dickman & Meyer, 1988) or sensation seeking (Krijns, Gaillard, Van Heck, & Brunia, 1994) may underlie differences in prioritization of speed or accuracy through differences in N1 amplitude. Individuals who self-report as being impulsive or sensation seeking tend to show faster speeds at the expense of accuracy whereas individuals who self-report as low-impulsivity tend to favour accuracy over speed. If a measure for impulsivity or sensation-seeking had been included in Study 1, it may have been possible to predict whether an individual would show response time costs and/or accuracy costs as a result of processing task-irrelevant distractors. However, based on the results from Study 3, it may not be possible to predict the *amount* of capture as impulsivity did not predict capture in any of the five capture measures. Nonetheless, it could provide a future avenue for better describing the style of attention capture more generally.

Finding 3: Attention Capture is Reliable

Study 2 provides, the first examination of test-retest reliability of several commonly used attention capture tasks with sessions spaced one week apart. In a relatively large sample, the expected pattern of capture was found in all tasks, and capture estimates were found to be reliable and stable within individuals over one week for all five measures of attention capture. Additionally, within-session reliability approximated test-retest reliability in all tasks. This finding suggests that, within a given task, attention capture is a stable individual trait.

The importance of this finding is twofold. First, beyond some within-session, split-half reliability estimates for some of these tasks (e.g., Kawahara & Kihara, 2011), no test-retest reliability examination had been conducted. Knowing the reliability of capture task measures is important for the development of theories regarding the nature of attention capture. Finding that a given measure of attention capture is reliable over time for an individual allows researchers to examine the underlying nature of capture in that task from an individual differences perspective – for example, by examining which individual differences predict who shows small or large capture on that task. Secondly, methodologically speaking, it is important to know the long term reliability of cognitive measures as the degree to which a measure correlates with itself sets an upper limit on the degree of relationship one would expect between that measure and any other measure. In this case reliability estimates set limits on the maximum that could be expected in terms of correlations with other measures of capture and with measures designed to predict individual differences in attention capture.

Finding 4: Attention Capture does not Generalize between Tasks

Knowing that individual differences in attention capture are stable over time within attention capture tasks, one can then examine correlations between capture tasks to see if individuals vary in their propensity to have their attention captured generally or whether this is task or paradigm specific. The hypothesis that an individual’s tendency to be captured by irrelevant stimuli in one task would be related to the likelihood of capture in another was tested.

A pattern of positive correlations between capture tasks could be explained by a common factor, for example, executive control, that operates across tasks. Such a pattern was not observed. This is somewhat concerning as attention capture tasks are often used interchangeably under a tacit assumption that they all measure the same general construct. Instead, the unique parameters of each task appear to drive the differences observed. A given individual shows stable capture for each task, but capture in a given task remains unrelated to capture in another task. The trait-like capture we observed appears to be highly task-specific. What is puzzling is that there would be such a stable mechanism for capture in an individual that is so strikingly unrelated to capture in other tasks performed by the same individual in the same experimental setting. It is somewhat disconcerting that the null correlations may be due simply to task parameters that may not have any obvious global theoretical implications.

The data were analysed in many ways (i.e., capture was analysed both as a difference score and a residual, with both Pearson and Spearman Rho correlations, and within each session and across sessions) but nothing worked to predict attention capture. It is unlikely that the measurement approach is responsible for the lack of relationships. A wide range of measurements was used to try to predict capture, which was itself measured in five different ways. Potential relationships were also tested across several separate experiments with different participant samples. So, there were many opportunities to find a relationship. That said, there is always an issue with interpreting or accepting a null result; there could be a way to predict attention capture, but it is currently unknown based on the presented results.

It seems unlikely that completely different attention mechanisms are recruited to perform each task—especially given that two capture measures are derived from the same task in some cases, yet they do not relate to each other. However, one possibility is that differences in how targets and distractors are weighted for attention across tasks may drive the null correlations between capture measures. For example, the valuations that guide attention may be task specific because they work not only on life-long learning, but also within the given context of each task. Different task contexts may therefore lead to different attentional valuations for different distractors for different individuals.

Take, for example, Banich's (2009) integrated "Cascade of Control" model of executive function which invokes a small network of brain regions (DLPFC, mid-DLPFC, and ACC) involved in developing and maintaining attentional sets. First, the posterior DLPFC selectively activates the appropriate sensory brain region for a given task. For example, if the task involves detection and filtering of stimuli based on colour (e.g., finding a green circle amongst red squares), it will activate visual colour areas. The exact specificity of such selective activation is unknown, but if we make the assumption that it can produce fine-grained and nuanced "choices" then we could speculate that different task parameters would bring about activation in comparatively unrelated brain areas and these "choice" weightings would likely differ consistently across tasks and individuals. Thus, instead of looking for commonalities between capture tasks, future studies might consider looking for coordinated functional overlap in brain activity. The key may be to examine activity in the posterior DLPFC as, according to Banich, this region appears critical to the differential recruitment of task-specific brain regions. Observable behaviour may differ, but this region may show consistency between tasks.

Finding 5: Attention Capture is Unrelated to Measures of Executive Control

Experiment 1 of Study 3 showed that individual differences in executive control of working memory (as measured by OPSAN scores) did not predict individual differences on any of the capture measures. This result is both disappointing--as it would have provided a simple explanation for capture--and exciting--as it suggests that attention capture is not rooted in working memory function as so many cognitive abilities are included in the strong relationship between fluid intelligence and OSPAN performance (Kane et al., 2004). Low OSPAN scores are associated with an increased likelihood of detecting one's own name in a dichotic listening environment (Conway, Cowan & Bunting, 2001). Although working memory capacity (as measured by OSPAN) to known to place high demands on executive function (Han & Kim, 2004; Kane, Bleckley, Conway, & Engle, 2001; Peterson, Beck, & Wong, 2008), we found no evidence that it can predict attention capture in the present set of tasks. One likely explanation is that the attention capture tasks used in the present body of work do not tap into the same executive function constructs as OSPAN. OSPAN may require a comparatively greater degree of executive function and additionally taps into encoding and retrieval processes compared to the rather lower-level filtering and inhibition as required in the capture tasks. OSPAN is an intensive task that requires the heavy use of executive function and working memory. Words must be memorized for later recall while simultaneously reading aloud and solving mathematical equations. Given that the parameters of the OSPAN and dichotic listening tasks overlap in terms of their auditory/phonological nature and a requisite high level of executive functioning, such a pattern should not be surprising. In contrast, the capture tasks used in the present body of work do not require the same degree of executive functioning and so do not overlap heavily with OSPAN parameters. This may offer the best explanation for why OSPAN did not predict attention capture here.

Indeed, working memory capacity is known to relate to visual search tasks that place high demands on top-down control where higher working memory capacity is associated with more efficient search, but not to visual search tasks that place relatively more demands on bottom-up mechanisms (Sobel, Gerrie, Poole, & Kane, 2007). This might have led to the prediction that OSPAN would be associated with only the contingent capture tasks where top-down control and attentional set maintenance are required for efficient search. This was also not the case. It is at least possible that, even in the contingent capture tasks presented here, bottom-up salience guided search more than top-down control settings. Some argue that contingent search, when based on the conjunction of two distinct target features such as colour and shape, can still invoke bottom-up mechanisms because the colour difference between targets and distractors is more salient than shape differences (Sobel et al., 2007; Sobel & Cave, 2002). If we can accept that capture measured in each of the tasks presented here was in fact driven by bottom-up mechanisms, then it is at least plausible that higher-order executive functions would not be brought online. This would manifest as a null correlation between, for example, OSPAN and capture measures.

Finding 6: Attentional Meta-Awareness does not Predict Capture

Study 3 included a large battery of questionnaires, including self-report measures of attentional control, impulsivity, and errors in day-to-day functioning. No evidence was found to suggest that attention capture could be predicted by any of the many self-report measures. Given that Study 2 showed null correlations between all the capture tasks, no universally predictive measure that would explain capture across all tasks was expected. However, to the extent that each self-report measure taps related, but somewhat different attentional control constructs, and to the extent that capture in each task is independently characterized by task parameters, capture in one or more tasks was expected to be predicted by one or more self-report measures. This was not the case. Given that the battery of self-report measures showed many inter-correlations, a factor analysis was conducted. This revealed what was essentially a two factor solution (1. Spontaneous errors; 2. Effortful persistence) that served to potentially strengthen the predictive utility of the self-report measures. However, these factors also did not predict capture in any of the tasks[9].

The self-report measures of day-to-day attentional errors ask about explicit events such as forgetting where one left his car keys or whether one tends to get distracted easily – questions which may tap different cognitive abilities or tap abilities more broadly than measuring the ability to resist interference from salient distractors in given life situations. For example, participants could be asked to rate the extent to which they experience difficulty remembering a phone number when someone else is talking, listening to a single conversation in a noisy café, trying to find a friend wearing clothes of a certain colour but falsely identifying a stranger wearing a similar colour. These explicit examples of contingent failures in daily life may serve as a better estimate of the less intuitive form of capture in the capture tasks.

However, the lack of generalisability in attention capture across tasks suggests that no self-report measure of daily attention would likely be able to predict attention capture. A more likely possibility is that, unlike day-to-day patterns of attentional failures and successes, attention capture is not a trait-like characteristic of individuals, and that the specific inhibitory and attentional weightings given to items within each task contribute to an individual’s attention capture scores within each task. It is possible then that capture is determined moment-to-moment by state and stimulus factors rather than by trait properties. Although capture itself is reliable and

[9] It is important to point out that the digit categorization task from Study 1 was not included in any of the subsequent studies, so it is at least possible that the lack of correlation between the self-report measures and attention capture may not extend to the cross-modal deviant paradigm used in Study 1.

the expected pattern of capture is observed in each task, individuals are not necessarily captured on every trial on which a distractor is presented. On average, distractors capture attention, but there may be other within-individual or momentary environmental factors that determine the likelihood of capture. This is the primary finding of Study 4.

Finding 7: Moment-to-moment Attentional Focus Predicts Moment-to-moment Capture

The results of Studies 2 and 3 led me to speculate that attention capture may be best characterized by moment-to-moment changes in attentional focus attention rather than individual traits. Although overall executive control scores may not predict attention capture at the level of the individual, the level of executive control displayed on a given trial of an attention capture task may have implications for the degree of attention capture observed on that specific trial. That is, processes engaged moment-to-moment may not be reflected in overall executive control scores or derived overall capture scores. Moment-to-moment lapses of attention, more commonly referred to as mind-wandering, are associated with errors in vigilance and an impaired performance on sustained attention tasks (Kane & McVay, 2012; Kane et al., 2007; Killingsworth & Gilbert, 2010; McVay & Kane, 2009). Mind-wandering could have impacted or modulated attention capture in several ways.

First, mind-wandering could have lead to slower performance overall. This pattern was observed in both the non-contingent and contingent visual spatial search tasks where RTs were longer for all conditions during which mind-wandering was reported. This result fits with other studies that find that mind-wandering, or task-unrelated thoughts, lead to careless performance and a slowing of RTs (Kane & McVay, 2012; McVay & Kane, 2012; Schooler et al., 2011) and suggests that during a mind-wandering episode, individuals may process stimuli only superficially and/or fail to initiate timely responses. This pattern also fits with Finding 6 that showed that self-reported general daily attentional errors were positively associated with speed of responding in the attention capture tasks. It is possible that when individuals report day-do-day errors, they are actually reporting on the negative effects of day-to-day mind-wandering.

Secondly, mind-wandering could have lead to greater capture by salient stimuli, leading to greater non-contingent capture in particular (see Kane & McVay, 2012; McVay & Kane, 2009, 2010). This hypothesis was supported by the finding that mind-wandering impairs the ability to inhibit shifts of attention to salient task-irrelevant stimuli, but only in the non-contingent search task. Here, the results showed an increased capture when mind-wandering in the non-contingent task, but non-significant reverse effects of mind wandering in the contingent task. This supports the idea that moment-to-moment drifting of attention away from the primary task influences the way in which critical distractors are processed and that mind-wandering may not have the same effect on attention capture in contingent search as in non-contingent search.

The results are in accord with the view that mind-wandering can lead to changes in default network activation and the misdirection of executive processes away from task-related stimuli (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Schooler et al., 2011; Smallwood, Brown, Baird, & Schooler, 2012; Smallwood & Schooler, 2006). During such misdirection, the attentional resources needed to build and maintain efficient attentional settings are impaired and participants may search in a salience-driven fashion. In the non-contingent version, failure to maintain an attentional set can lead to increased salience-driven capture as the target is not highly salient compared to the lone red distractor. Thus, if mind wandering leads to an increase in the use of salience and a decrease in the use of a top-down attentional search-set, then in non-contingent search, mind wandering will bias participants away from the less salient target and towards the more salient distractor, resulting in increased capture.

In the contingent version, failure to maintain an attention set would lead to less capture by distractors that share a feature with the target stimulus, potentially mitigating capture effects. In the distractor condition of contingent search, participants are looking for a green circle, thus other green items in the search array may capture attention. But assuming a development of a contingent search set has been disrupted by mind-wandering, search would become salience-driven. This should result in a pattern similar to non-contingent search. However, in the distractor-present condition, two salient green items are presented. If search is purely salience-driven, both stimuli would be equally salient which would result in correct identification of the target of half of the trials. This may serve as a benefit for contingent search; in contrast to non-contingent search where the most salient stimulus is always a distractor, in the contingent search condition attending to the salient items would lead one to attend to one of the two items that are both consistent with the colour contingent search.

I also found that individuals tended to mind-wander equally in both tasks. Thus, the different effect of mind-wandering for contingent versus non-contingent is not attributable to different levels of mind-wandering overall. The null correlation between the capture costs observed in each task is not attributable to differences in overall mind-wandering proportions (c.f., Forster & Lavie, 2014). It is also important to note that the proportion of mind-wandering did not predict capture in either of the tasks which further reinforces the notion that attention capture is best characterized by moment-to-moment state effects.

Modern imaging techniques can provide insight into such moment-to-moment effects. There is already some evidence for the activation of key default mode network brain regions during mind-wandering. Both the default mode network and the executive network regions tend to be most active when participants unknowingly mind-wander (Christoff et al., 2009) suggesting that it is most pronounced when it lacks meta-awareness. Increased default network activation during a mind-wandering episode may lead to a more superficial processing style which could lead to an attentional setting that detects only the most salient stimulus in the visual array similar to what might be predicted by the view that all search can be salience-driven in the right circumstances (Awh, Belopolsky, & Theeuwes, 2012; Sobel et al., 2007; Sobel & Cave, 2002). Future studies using neuroimaging techniques during the tasks could explore the possibility that mind-wandering (vis. executive failure) disrupts the ability to form and maintain an attentional set leading to differential performance in contingent and non-contingent attention capture tasks.

There is one methodological limitation to Study 4 that is worth briefly discussing. Mind-wandering probes were presented to participants randomly, on average every 16 trials, to ensure that the nature of the capture task was not altered by the probes. This resulted in an very uneven distribution of data points across conditions, forcing me to base the analyses on the average response time from two trials (rather than one trial) preceding each mind-wandering probe. Although an interesting pattern emerged, it might be informative to reduce the time-frame to the single trial immediately before each mind-wandering probe. This is especially critical for the argument that moment-to-moment fluctuations in attentional focus dictate capture as moments may be very fleeting, thereby influencing what happens during trial n-1 versus trial n-2. Indeed, additional analyses of the one-trial-back means actually showed a more pronounced three-way interaction between task, distractor, and mind-wandering than reported with the two-trials-back means, but there was a large degree of error around them, and many additional participants were excluded from the analysis due to not having at least one data point for each cell, which reduced the ability to support the effect statistically.

Future Directions

The overall findings present many cases where our prevailing and intuitive understanding of attention capture have been challenged. Many possibilities for explaining individual differences in attention capture have been eliminated and overall the results suggest that attention capture might be better explained at the trial-to-trial level as opposed to using the level of the individual, and within attention capture paradigms, as opposed to across, attention capture paradigms. The current results suggest that moment-to-moment attentional drifting plays a role in attention capture. The default mode network, which is associated with the presence of mind wandering, comes online only when task demands are low, when participants are not motivated to perform, or are simply bored (see Eastwood, Frischen, Fenske, & Smilek, 2012), conditions which are common in relatively monotonous cognitive lab tasks such as those used here.

It may be useful to explore the role of moment-to-moment mind-wandering in other capture tasks. In Study 4, we examined only the two spatial visual search tasks because they were found to be the most reliable of the set of capture tasks examined in Study 2. We could also purpose-build each of the remaining tasks to determine whether mind-wandering in the moment might predict capture in those tasks as well. If so, it would make a strong case for moment-to-moment cognitive control effects in the prediction of capture. Additionally, it may be helpful to re-build the spatial capture tasks so that mind-wandering probes are presented equally often in both the distractor-absent and distractor-present conditions. This would increase the likelihood of producing a balanced distribution of mind-wandering responses across both conditions and allow for the use of the one-trial-back data which showed a numerically more compelling pattern of means.

A seemingly fruitful general approach to understanding attention capture would be to use electrophysiological or neuroimaging methods to examine trial-to-trial performance variation in attention capture. One promising avenue is the notion that default mode network activity and prefrontal executive control systems may trade-off moment to moment and that neurophysiological evidence of this trade-off could be used to predict capture trial-by-trial. The high temporal resolution provided by electrophysiological approaches provides the opportunity to describe the time course for attention capture. Further, given that some evidence holds the default network responsible for failures in sustained attention, it makes a good candidate for predicting moment-to-moment capture.

Other studies of exogenous attention capture have revealed the dorsal and ventral attention networks (DAN and VAN, respectively) as two key circuits underlying capture (see Carretié, 2014, for a review). The DAN is sensitive to emotional or otherwise high priority stimuli and comprises areas such as the intraparietal sulcus whereas the VAN is responsible for reorienting internal processes to externally directed processes and comprises brain areas such as the inferior frontal gyrus and temporo-parietal junction. In terms of electrophysiological components, P2 and the family of N2 components have been heavily implicated in studies of exogenous attention. For example, the N2pc is known to reflect the allocation of attention to lateralized visual targets (Hickey, McDonald, & Theeuwes, 2006). The results of Hickey and colleagues’ 2006 study showed that an N2pc could be elicited for both targets and salient distractors and that the distractor-elicited N2pc occurred before the target-elicited N2pc. This pattern suggests that attention would be shifted to salient distractors before shifting again to the target.

This approach could be adopted to test the moment-to-moment search strategies employed by participants in the present set of studies. Chapter 5 found that, compared to no reported mind-wandering, in-the-moment mind-wandering led to greater capture in non-contingent visual search, but less capture in contingent visual search. Measurement of N2pc could provide support for the suggestion that mind-wandering leads to a superficial processing style in which attention settings detect only the most salient stimulus in the visual array. By carefully lateralizing targets and distractors in the spatial search tasks, one could compare N2pc amplitudes for distractors on mind-wandering versus non-mind-wandering trials. One might expect to see higher distractor-elicited N2pc amplitudes for mind-wandering episodes during non-contingent than contingent search as distractor salience in contingent search requires use of modified attentional settings.

Final Thoughts

Attention is the set of processes by which environmental stimuli are allowed to enter consciousness. Attention is inherently selective. Even in seemingly simple laboratory experiments, so much information is available to individuals at any given moment that attention must work to sort out the material that is most relevant to our current goals and needs. It prioritises stimuli based on personal or task-specific goals (e.g., contingent visual search) or based purely on stimulus salience (e.g., non-contingent visual search). In this way, attention can be modulated by either top-down or bottom-up processes or both. Attention capture, although reliable and seemingly trait-like in any given task, is difficult to predict—it does not generalize across capture tasks or relate to other measures of executive control.

Instead, the results show that capture must be based on much more fluid and context-specific factors that are difficult to systematically isolate. It involves the parallel coordination of an extensive neural network of brain areas. Instead of viewing attentional capture in strict forms such as contingent or non-contingent or as spatial or temporal that respond to situations that best suit each type, a more dynamic perspective may be required. Capture may be an emergent phenomenon that is brought about only by the interaction between numerous factors that comprise a given attention capture episode (e.g., task parameters, environmental factors, individual differences, among many others). The finding that moment-to-moment fluctuations in attentional focus provides the strongest predictor of attention capture provides support for an emergent perspective—that capture depends on the unique structure of each individual's biological brain structure, past experience, development, and situation factors brought to bear on the current episode (Courtney, 2004). The attention capture we observe may be a product of a complex interaction between context-dependent and dynamic neural processes (Uithol, Burnston, & Haselager, 2014). Of course, working to account for every imaginable factor contributing to such a complex system would result in a model that is no simpler than the system being explained. This is not to suggest that working to understand attention capture is a futile endeavour. Instead, this should encourage future studies to focus on predicting the factors that contribute to in-the-moment fluctuations of attentional focus.

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